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Economic Evaluation Associates, Inc, Chicago, IL

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1) deletes the general water quality standard for phosphorus of 0.05 mg/l, and

2) adds a new effluent standard for phosphorus (1.0 mg/l) for discharges affecting lakes and reservoirs of 20 acres or larger.

In addition, the proposed amendment would change certain portions of the effluent standards to make them compatible with the National Pollution Discharge Elimination System (NPDES). These latter changes are largely administrative, with no significant environmental or economic consequences.

The proposed regulatory action was designated as PCB R76-1 (Appendix A), and was published in the "Environmental Register" #118, January 27, 1976.

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State of Illinois
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NOTE

This report has been reviewed by the Institute for Environmental Quality and approved for publication. With the exception of the Opinion of the Institute's Economic Technical Advisory Committee, views expressed are those of the contractor and do not necessarily reflect the position of the IIEQ.

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Opinion of the Economic Technical Advisory Committee of the Illinois Institute for Environmental Quality

The Economic Technical Advisory Committee has reviewed the economic impact study, IIEQ Document No. 78/24, entitled Economic Analysis of Phosphorous Control and Other Aspects of R76-1. The Committee finds the report to be generally responsive to the requirements of Section 6 of the Environmental Protection Act, and recommends that it be forwarded to the Pollution Control Board so that public economic impact hearings may be held in connection with proposed regulation R76-1, PHOSPHOROUS WATER QUALITY STANDARDS, which seeks to amend Chapter 3, Water Pollution Regulations.

TABLE OF CONTENTS

Page

SUMMARY . . . .

Chapter

1. THE EUTROPHICATION PROCESS . . . .
2. COSTS OF PHOSPHORUS REMOVAL . . . .
3. ENVIRONMENTAL IMPACT OF THE PROPOSED PHOSPHORUS REGULATION . . .
4. BENEFITS OF PHOSPHORUS REMOVAL . . . .
5. SECONDARY IMPACTS ON THE ILLINOIS ECONOMY . . . .

Appendices

1. . . . .
2. . . . .
3. . . . .
4. . . . .
5. . . . .

FOREWORD

The Institute normally publishes manuscripts as received from its contractors. In this case, however, the descriptive material and model output were so voluminous as to preclude the usual printing and distribution practices.

The abridged version presented here was prepared by the authors. The unabridged version is available at the Institute's library.

The authors' analysis of the recreational value of improved water quality has included, for the first time in Institute studies, a concept based on the public's willingness to pay for recreation. The detailed explanations of "consumer surplus" (net benefit) and the travel cost method of demand analysis have been retained as a guide to future contractors who may choose to use this analytical method.

SUMMARY

On January 5, 1976, the Illinois Environmental Protection Agency proposed an amendment to the Water pollution Control Regulations (Chapter 3) which:

1. deletes the general water quality standard for phosphorus of 0.05 mg/l, and

2. adds a new effluent standard for phosphorus (1.0 mg/l) for discharges affecting lakes and reservoirs of 20 acres or larger.

In addition, the proposed amendment would change certain portions of the effluent standards to make them compatible with the National Pollution Discharge Elimination System (NPDES). These latter changes are largely administrative, with no significant environmental or economic consequences.

The proposed regulatory action was designated as PCB R76-1 (Appendix A), and was published in the "Environmental Register" #118, January 27, 1976.

Reason for the Proposed Regulation

There is no phosphorus effluent standard except for dischargers to Lake Michigan and the Fox River (1 mg/l). The reason for establishing a general effluent standard for phosphorus (1.0 mg/l) stems from Rule 402 of Chapter 3, Water Pollution Regulations, which states that where a water quality standard is violated the Agency (IEPA) shall take action to require dischargers to meet whatever effluent limits are necessary to ensure compliance with the standard. Since most natural waters in Illinois violate the 0.05 mg/l phosphorus water quality standard, the Agency must therefore limit dischargers which are tributqry to lakes and reservoirs to an effluent standard which is equal to the water quality standard, namely 0.05 mg/l.

Organization of the Study

The study begins with a discussion of lake and stream eutrophication--

which is what the phosphorus standard is intended to control. This is followed by calculations showing, for a number of assumptions, the cost of meeting the proposed 1 mg/l phosphorus standard. Also included is an estimate of the cost of meeting the 0.05 mg/l standard which would apply to certain dischargers if the proposed new standards were not adopted.

The difficult part of the study is the estimation of the environmental effects and benefits which would accrue if the proposed standard was adopted and enforced.

Findings of the Study:

The study concludes that because of the pervasive influence of nonpoint sources, the 0.05 mg/l phosphorus water quality standard is not achievable. The standard is deleted in favor of a new effluent standard for point sources which are tributary to lakes and reservoirs of 20 acres or larger. The annual cost to the 27 municipalities affected by the new effluent standard would range from $525,853 to $998,516. If the municipalities were required to meet the 0.05 mg/l water quality standard, the cost would be approximately $3.2 million annually.

Stated differently, the proposed standard will require 27 municipalities to expend a total of from $0.5 to $1.0 million to control phosphorus discharges--an amount not now being spent. By relieving them of a requirement to meet an unrealistic water quality standard. these municipalities will avoid an additional annual expenditure of $2.2 to $2.7 million.

In their effort to predict the environmental impact of the proposed phosphorus standard the authors employed a mathematical model developed by Vollenweider and used to analyze the trophic state of over 800 U.S. lakes and reservoirs. In addition, the authors employed a discriminant analysis technique to establish the probability of correctly classifying a lake as eutrophic or oligotrophic using the Vollenweider variables (i.e., phosphorus loading, mean depth of water, and residence time). Of 28 Illinois lakes examined by this technique, only one seems capable of achieving oligotrophic staus under the proposed regulation. The Vollenweider analysis does show that reductions in phosphorus loading will increase the probability that the lakes will become oligotrophic. However, the authors interpret the low probabilities predicted by this analysis to mean that improvement in the trophic status of Illinois lakes may take a longer time than anticipated. In fact, the low probability of improving the trophic status of Illinois lakes suggests the possibility that no benefits will come from phosphorus removal regardless of the standard imposed.

If the impact of the proposed phosphorus effluent standard is an improved trophic status of certain Illinois lakes, the most tangible (primary) benefits will accrue from water based recreation. Secondary benefits (which are not properly considered in cost-benefit comparisons) would also accrue from increased employment and earnings resulting from the increased recreational use of those lakes.

Primary benefits were estimated by the travel cost method of demand analysis. The analysis seeks to determine a maximum willingness to pay for recreation, and to use the total willingness to pay as a net benefit. Demand curves were constructed for several important lakes. This procedure required knowledge of the population distribution and distance to 23 large population centers from nine Illinois lakes. It was assumed that these urban centers accounted for one-half of the total visits to the nine lakes. The results of the analysis suggest that total annual recreational benefits for the nine lakes are about $54 million. This means that a 1 percent change in recreational use would be worth about $540,000.

As a means of comparing the costs and benefits of the proposed regulation, the authors devised a scenario which assumed no water quality improvement until 1990, a 1 percent recreational benefit during the period 1990 to 2000 and a 5.3 percent change in usage thereafter. Under these circumstances, the recreational benefits would be roughly equivalent to the cost of the proposed effluent standard of 1.0 mg/l for the 27 municipalities.

An analysis of secondary economic benefits suggests that a 1 percent increase in lake visitations would stimulate Illinois output by $1.47 million.

The number of jobs associated with urban and non-urban expenditures at the six lakes is estimated at the present, in 1990, and in 2000 as 4,830, 7,120, and 7,950 respectively (assuming adoption of the proposal).

In summary, the authors estimate the following impacts of the proposed regulation:

a. There would be no significant effect of the cost or availability of goods and services in Illinois.

b. Employment in the vicinity of the six Illinois lakes could increase by about 3,000 by the year 2000.

c. There would be no significant impact of the proposed regulation on agriculture, the cost of food, or on agricultural employment.

d. The cost of sewerage services to the 27 municipalities affected by the proposed regulation will total about $0.5 to $1.0 million.

e. There will be no significant impact of the proposed regulation on Illinois commerce and industry.

A second major provision of the proposed amendments would strengthen the suspended solids effluent requirements from 37 mg/l to 30 mg/l. Other sections relate to compliance dates, measurement procedures and definitions.

The proposed revision to the control of suspended solids is advanced in order to make Illinois regulations consistent with Federal requirements. It is believed that the new standard would be easily achievable, given that the existing BOD standards are being met. Similarly, other changes are proposed to bring Illinois law into conformity with Federal requirements and procedures, and also to clarify the intent of existing State regulations. These proposals are expected to have no significant economic impact.

CHAPTER 1

THE EUTROPHICATION PROCESS

This chapter begins with a discussion of some of the basic terms employed throughout this study. The deleterious consequences of eutrophication are explained as well as some beneficial effects commonly associated with eutrophication of lakes. The concept of a limiting nutrient is introduced. The chapter concludes with a discussion of phosphorus control as a method of reducing the eutrophic condition of lakes.

Definitions

The word eutrophic is based on the Greek word meaning well-nourished. With respect to lakes, it is used to mean a lake with a high potential concentration of nutrients. The opposite situation to a well-nourished or eutrophic lake is a poorly nourished or oligotrophic one. Mesotrophic lakes are intermediate. The potential concentration rather than the actual concentration of nutrients is used since at any one time, much or all of the nutrients in a lake may be tied-up in the plants, animals or sediments.

Eutrophication is the term used to describe the process of a lake becoming more nourished and/or productive. It is generally caused by an increase in the input of nutrients to the lake.

Another important measure of the state of a lake, which is related to its trophic status, is the productivity of the lake. The productivity means the amount of plants and animals which grow per unit area of the lake over some time period. Primary productivity refers to the amount of carbon dioxide converted to carbohydrates and other energy containing compounds by plant photosynthesis in the lake. The plants involved are usually the one-celled plants called algae, but in the shallow lakes rooted plants may also be involved, The energy stored by photosynthesis in the plants is very important as the plants serve as the food source for the animals in the lake and thus are the ultimate source of energy for all of the life in a lake.

A high concentration of nutrients in a eutrophic lake can support a higher concentration of plants. This results in a high productivity for those lakes. Conversely, the productivity of oligotrophic lakes will be low.

Effects of Eutrophication

In recent years, lakes said to be undergoing eutrophication and lakes described as eutrophic have been held in low repute. However, like most changes, there are both beneficial and detrimental effects.

An example of a beneficial change with eutrophication is the increase in the size and/or numbers of fish in the lakes associated with increasing eutrophication. Thus farmers have often added nutrients (fertilizers) to their farm ponds to increase the yield of fish from these ponds. Also, while Lake Erie is the most eutrophic of the Great Lakes, it also supports the largest commercial fishery on the Great Lakes.

Most of the detrimental effects of eutrophication are due to the higher numbers of organisms present in eutrophic lakes. The numbers of algal cells is often high enough that the water has the appearance of pea-soup. These problems are particularly severe with blue-green algae. The cells of some of the blue-green algae, rather than being independent of one another as in other algae, collect together in dense colonies, forming floating mats on the surface of the lake. These are unsightly, they discourage swimming and water skiing, and often give off disagreeable odors.

In shallow lakes, the densities of rooted plants may become quite large and also adversely affect the use of the lake for recreational purposes. Thus, contrary to the common conception of eutrophic lakes as dead lakes, these problems are caused by too much life.

The biggest problem in most eutrophic lakes is caused by the depletion of the oxygen in the water upon the death of the large numbers of organisms present. While it is true that oxygen is released when the plants carry out photosynthesis in the sunlight surface waters, when the plants and other organisms in the lake die, they sink to the bottom and decay (are decomposed by bacteria and other microorganisms). This decay requires oxygen and the consumption of oxygen by the decay of the dead organism can seriously deplete the water of its dissolved oxygen. Then the fish and the other organisms which require oxygen are unable to live in these waters. Also, anerobic organisms which grow under these conditions often generate hydrogen sulfide and other noxious gases.

This problem is most severe in deeper lakes which stratify in the summer. The stratification very effectively isolates the bottom waters from the surface waters and the oxygen in the atmosphere. Thus the oxygen present in the bottom waters when the lake stratifies in the spring must last until the fall overturn of the lake. If the biological oxygen demand (BOD) in these waters exceeds the dissolved oxygen (DO), the water will become anerobic before the fall. Similar problems arise in lakes where the surface is totally frozen for long periods in the winter and the reserves of DO are insufficient to last until the spring thaw. It is the eutrophic lake which becomes anerobic that is more appropriately said to be "dead."

A final effect of eutrophication is that it changes the environment of the lake. Different species of algae, rooted plants, zooplankton and fish inhabit eutrophic lakes than oligotrophic lakes. Thus, the more eutrophic a lake becomes, the less it resembles its natural condition. This is often interpreted as being deleterious.

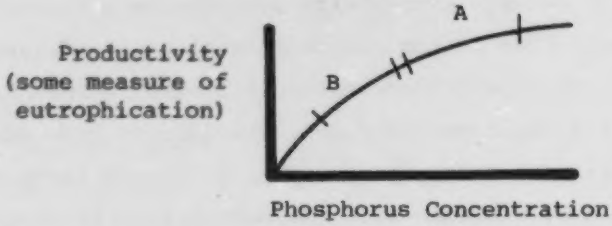
Eutrophication Process

In order to understand eutrophication and also be able to devise workable strategies to combat it, an understanding of the limiting nutrient concept is important. All organisms require certain essential nutrients for growth and reproduction. The ones required in the highest amounts are carbon, hydrogen and oxygen, all of which are readily available in the form of water and carbon dioxide. The next largest requirements are for nitrogen and phosphorus. Another twenty elements, including iron, zinc, copper and sulphur are required in small amounts. These 25 or so essential nutrients are required in specific ratios to one another. For instance, the average chemical composition for the five major elements in fresh water algae is $C \cdot H \cdot O \cdot N_{14}P_1$. Neglecting the available carbon, hydrogen and oxygen, the ratio of the atoms of nitrogen to phosphorus required for growth is 14:1 (6.5:1 on a weight basis).

> It is now quite apparent that we should think not of oligotrophic or eutrophic water types, but of lakes and their drainage basins and sediments as forming oligotrophic systems.[1]

This recognizes that a lake is not isolated but dependent on its surroundings for its inputs. The lake becomes eutrophic because its drainage basin has become eutrophic. To attempt to reverse eutrophication of the lake without doing something about the basin will not meet with success. For the lake to return to an oligotrophic state, the basin, or its outputs to the lake, must also return to that state.

Unfortunately, it is often very difficult to get dramatic changes to occur, no matter what is done. The reason is that the relationship between the productivity of a lake and its phosphorus content in not linear but is rather as shown in Figure 1. For a lake which falls in the B region of the curve, chiefly mesotrophic lakes, a reduction in the phosphorus inputs, and therefore the phosphorus concentration in the lake, would show a corresponding reduction in obvious eutrophication problems. Most eutrophic lakes, however, fall into the A part of the curve. Thus to get dramatic improvements, the phosphorus concentration must be greatly reduced. Thus the inputs of phosphorus must be greatly reduced.



It is often pointed out that many eutrophic lakes are nitrogen limited. Thus, it would seem to make sense to control nitrogen rather than phosphorus in these lakes. There are four reasons why this is not a good strategy.

1) The lakes were originally phosphorus limited and the changes in

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[1] Hutchinson, G. E. In Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, 1969.

the lake were caused principally by the addition of phosphorus to the lake. There is no way the lake can return to an approximation of its natural state without the phosphorus inputs also returning to their former levels.

2) Nitrogen removal is technically more difficult and economically more expensive than is phosphorus removal.
3) A larger percentage of the phosphorus occurs in more easily controlled point sources.
4) It has been recently demonstrated that phosphorus should be the ultimate limiting nutrient in all lakes.[1]

The last reason is the most important. The rationale for it is that besides carbon, hydrogen and oxygen being readily available from the atmosphere to organism in lakes, nitrogen is also available. While nitrogen gas cannot be utilized as a nitrogen source, some plants, blue-green algae in particular, are able to convert atmospheric nitrogen to a form able to be utilized as a nutrient. This is the reason that blue-green algae are so prevalent in eutrophic lakes which are nitrogen limited. The blue-green algae, being able to fix their own nitrogen, are able to grow while the other algae cannot. Controlling nitrogen inputs then will only serve to stimulate the biological fixation of nitrogen with the concomitant increase in the types and number of the often noxious blue-green algae.

The implications of phosphorus being the ultimate limiting nutrient, are that lakes which are now nitrogen limited, and which have constant nitrogen and phosphorus inputs, are not yet at a steady state with respect to nitrogen. Thus, biological nitrogen fixation will be stimulated until the total output is such that phosphorus again becomes limiting.

The benefits derived from phosphorus removal from waste water treatment plants are calculated on a total phosphorus basis. This type of calculation underestimates the benefits of this phosphorus removal. The reason is that not all of the phosphorus in a lake or in a discharge to a lake can be utilized by the organisms in that lake. Only that which is orthophosphate or is converted to orthophosphate in the lake is available for uptake by organisms.

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[1] Schindler, D. W. Evolution of Phosphorus Limitation in Lakes. Science 195, 260.

The percentage of phosphorus which is available in waste water effluents is quite high, usually greater than 80 percent. Conversely, the percentage of phosphorus from indirect sources--erosion, etc. is usually much less than 50 percent. Thus,removing one pound of phosphorus from waste water effluents is equivalent to removing 2 or 3 pounds of phosphorus from other sources.

Some evidence for this are the results of Sader and Wiersma which show that 46 percent of the phosphorus discharged to the Fox River in Wisconsin is available, but only 23 percent of the phosphorus which reaches Lake Michigan is available.[1]

For many lakes it will take a considerable reduction in phosphorus inputs to move a lake from being eutrophic to being mesotrophic. This is because the lakes are presently on the right-hand portion of the graph on Figure 1, and also because many of them are presently nitrogen limited. While some reduction should slow or halt the eutrophication process, the signs of improvement in terms of numbers of organisms or productivity may not be apparent. However, it should be beneficial if the reduction in phosphorus inputs leads only to making phosphorus the limiting nutrient again. Not only will this halt further eutrophication, but it should also greatly diminish the problems with blue-green algae. In addition, the lake should now be in such a state that further reductions in phosphorus inputs will show much greater improvements in water quality. While still eutrophic, some of the properties of the lake may be improved enough to permit more recreational use of the lake.

For many lakes, the increased productivity of fish associated with some eutrophication is an important benefit and one that would make it difficult to justify a return to an oligotrophic state.

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[1] Sader, P. E. and J. H. Wiersma, Phosphorus Sources for Lower Green Bay, Lake Michigan, J. Water Poll. Cont. Fed., 47, 504.

REFERENCES

1. Hutchinson, G. E. In Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, 1969.

2. Schindler, D. W. Evolution of Phosphorus Limitation in Lakes. Science 195, 260.

3. Sader, P. E. and J. H. Wiersma, Phosphorus Sources for Lower Green Bay, Lake Michigan, J. Water Poll. Cont. Fed., 47, 504.

CHAPTER 2

COSTS OF PHOSPHORUS REMOVAL

Impacted Municipalities

We identified dischargers that would be impacted by the proposed phosphorus regulation by gathering information from three sources. The USEPA National Eutrophication Study, Working Paper series identified several point source dischargers whose effluents are tributary to certain lakes or reservoirs of 20 acres or more [1]. Next, we consulted scores of maps in a series marked as IEPA, Division of Water Pollution Control--Planning and Standards Section, Water Quality Unit. Dischargers were located on these maps and their flows traced to determine whether effluents were tributary to a lake or reservoir of 20 or more acres. Finally, we secured a list of dischargers that the IEPA felt would be impacted by the proposed rule change. This list contained the names of some dischargers we had identified by other means, and it was particularly helpful because it identified many dischargers we had not been able to identify.

Our cost estimates are based on the IEPA's list which contains 27 municipal Waste Water Treatment Plants (WWTP). We had located some dischargers that are not in that group, but they are omitted from the analysis for one of three reasons: (1) they are industrial dischargers whose effluents are low in phosphorus; (2) their discharge is not 1,500 or more population equivalents; and (3) their discharge is tributary to a river slough which we did not consider to be a lake or reservoir.

Table 1 contains a list of impacted dischargers, the lake or reservoir to which the discharge is tributary, and the population served by the municipal WWTP. Cost estimates that will be presented subsequently, depend on flows which in turn depend on population served. Calculations assume that the

TABLE 1.--Municipal Dischargers Impacted by Proposed Regulation

Sewage Treatment Plant	Population Served in 1970	Lake Receiving Discharge
Arcola	2,276	Charleston
Arthur	2,214	Shelbyville
Auburn	2,594	Springfield
Bement	1,638	Shelbyville
Benld	1,736	Lou Yaeger
Farmer City	2,217	Clinton
Fisher	1,525	Decatur
Gibson City	3,454	Decatur
Hoopeston	6,461	Vermillion
Le Roy	2,435	Clinton
Marion	11,724	Crab Orchard
Monticello	4,130	Decatur
Mt. Vernon	16,382	Rend
Mt. Zion	2,343	Decatur
Pana	6,326	Carlyle
Pawnee	1,936	Springfield
Paxton	4,373	Decatur
Rantoul	25,562	Decatur
Shelbyville	4,887	Carlyle
St. Elmo	1,676	Carlyle
Sullivan	4,112	Shelbyville
Tolono	2,027	Charleston
Tuscola	3,917	Charleston
Vandalia	5,160	Carlyle
Villa Grove	2,605	Charleston
Virden	3,504	Springfield
Urbana	20,000	Shelbyville

population served, and therefore costs, will change at the same growth rate as projected for the county in which a WWTP is located.

Scope of Chapter

The analysis concentrates on phosphorus removal by chemical precipitation. Effectiveness and costs depend on many variables, such as effluent control techniques currently in use, flow levels in WWTP, utilization of capacity, chemical costs, land costs , etc. This chapter will show cost estimates calculated from a range of values for each variable. These cost estimates are summarized in tables thruout this chapter. A computer program, called COST, was developed to arrive at cost. This chapter also contains cost estimates on a "cents per 1,000 gallons" basis for various types of dischargers.

Phosphorus Removal by Adding Metal Salts

Phosphorus removal by means of a mineral addition is a well-established technique (2, p. 4-1). By adding aluminum or iron salts during primary treatment, not only can phosphorus be removed, but significant increases in removals of both suspended solids and BOD can occur (2, p. 4-1). This reduces the amount of waste activated sludge and can lead to reduced air requirements for aeration (2, p. 4-10, 3, p. II 17,19). Mineral additions can result in more total sludge and, therefore, costs above those directly allocated to the chemical treatment process.

We estimate costs for impacted WWTP by assuming that they would modify their operations by adding either aluminum or iron salts. The COST program assumes:

1. A sewage treatment plant adds liquid alum or ferric chloride to the influent.[1] The choice between liquid alum and ferric chloride depends on the relative costs, dosage requirements, shipment charges, and additional sludge costs related to the two chemicals.

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[1] Costs using dry alum also were estimated. However, given the price of dry alum at $129 per ton and the proximity of a typical impacted WWTP to sources of supply, we have determined that usage of liquid alum would be less costly than dry alum.

2. The influent contains 10 mg. or 11 mg. of phosphorus (as P) per liter. The average total phosphorus concentration in domestic sewerage (due to both human excretions and detergents with phosphate builders) is estimated to be in the range of 10 to 11 mg/l (2, p. 2-1; 3 p. II 1, 2).

3. 90% reduction in phosphorus concentration is required to meet the proposed rule. With 90% reduction, approximately 1 mg/l of P would remain in the effluent assuming 10 mg. or 11 mg. of phosphorus in the influent.

4. The aluminum to phosphorus, or iron to phosphorus mole ratio required for 90% phosphorus reduction is in the range of 1.8:1 to 2.1:1 (2, p. 3-3).

5. Updating construction and capital costs to July, 1977 was accomplished by using the USEPA's 5 mgd WWTP Index (reference base, 3rd quarter 1973 = 100) which stood at 116.2 as an average for 1976. The value of this index in July, 1977 was estimated as 122.0 (4, p. 98). Inflation of costs to a 1977 basis is necessary because available capital cost estimates are on a 1973 or 1974 basis.

6. Variable costs of sludge handling were estimated as of February, 1973 and updated to July, 1977 by using the Wholesale Price Index for Industrial Commodities which was estimated to be 194.8 in July, 1977. The same index was 120.0 in February, 1973 and has, therefore, increased by 162% = (194/120) since that time (5; 3, p. B-1, B-3).

7. The cost of liquid alum (on a 17% Al_2O_3 basis) is $79 per ton or $.0395/lb (6, p. 38). Ferric Chloride costs $100 per ton or $.05/lb (6, p. 42).

8. Shipment costs for liquid were obtained from trucking companies. We calculated shipment costs for liquid alum between each WWTP and two locations in Illinois--Joliet and East St. Louis. Liquid alum is available from manufacturers located in both cities. It was assumed that each WWTP would purchase liquid alum or ferric chloride from the closer supplier and thus minimize transportation costs. Ferric chloride can be purchased from a Northern Illinois manufacturer, but we were unable to ascertain whether there is a bulk supplier closer to Southern Illinois locations. If not, shipment costs may be slightly understated for ferric chloride.

9. One population equivalent is assumed to represent 100 gallons of water per day (2, p. 2-1).

10. Flows are based on the 1970 population served by a WWTP updated to the present by using county-wide population projections. Costs for years beyond 1977 are based on county-wide population projections to the year 2000 (10). These projections are for the years 1980, 1985, 1990, 1995 and 2000. We calculated growth rates between these bench-mark years and applied those rates to the appropriate years.

A typical output of the COST program is shown in Table 2, and Appendix 3 contains a sample calculation which shows the step-by-step procedures followed in the COST program. The footnotes of Table 2 show the assumptions used to generate the subsequent cost estimates. Several cost estimates are of particular interest: (1) Chemical and related freight charges would be $533,079 for an alum addition; (2) Total yearly costs, including chemicals, sludge and amortized capital costs, are $949,666.[1] The present value of future expenditures (over the expected life of capital equipment or to year 2000) is $8,680,590. Finally, the future value of expenditures accumulated to year 2000 is $64,238,400. The two later estimates refer to the same stream of expenditures, but only differ in regard to their time reference point.

Many reasonable assumptions can be made to describe important variables used in the COST program. These are listed below:

A. Discount Rate

Notation	Rate
A1	.08
A2	.09
A3	.10

B. Mole Ratio of Aluminum to Phosphorus

Notation	Mole Ratio
B1	1.80:1
B2	1.95:1
B3	2.10:1

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[1] Capital is amortized over 22 years rather than the 20-year period used in several sources. This leads to slightly lower yearly capital costs. A 22-year period was chosen in order to make the comparison between costs and benefits more meaningful since benefits are calculated to year 2000 or approximately 22 years after the proposed rule change would take effect.

TABLE 2.--Cost of Phosphorus Removal for One Treatment Alternative (Alum)

Sewage Treatment Plant	Lake Receiving Discharge	Yearly Chemical Cost	Total Yearly Cost Chemicals, Sludge, Amortized Capital	Present Value of Future Expenditures	Future Value of Expenditures in Year 2000
		(Costs in Millions of Dollars)			
Arcola	Charleston	$0.008	$0.016	$0.144	$1.065
Arthur	Shelbyville	0.008	0.016	0.141	1.047
Auburn	Springfield	0.009	0.018	0.171	1.266
Bement	Shelbyville	0.006	0.013	0.113	0.833
Benld	- - -	0.006	0.013	0.119	0.883
Farmer City	Clinton	0.008	0.016	0.140	1.033
Fisher	Decatur	0.005	0.012	0.111	0.819
Gibson City	Decatur	0.011	0.021	0.184	1.358
Hoopeston	Vermillion	0.023	0.041	0.364	2.697
Leroy	Clinton	0.010	0.019	0.179	1.328
Marion	Crab Orchard	0.045	0.077	0.701	5.186
Monticello	Decatur	0.015	0.028	0.242	1.790
Mt. Vernon	Rend	0.060	0.010	0.935	6.918
Mt. Zion	Decatur	0.009	0.017	0.153	1.133
Pana	Carlyle	0.022	0.040	0.352	2.606
Pawnee	Springfield	0.007	0.014	0.134	0.994
Paxton	Decatur	0.014	0.026	0.226	1.674
Rantool	Decatur	0.091	0.015	1.447	1.071
Shelbyville	Carlyle	0.017	0.032	0.280	2.069
St. Elmo	Carlyle	0.006	0.013	0.113	0.834
Sullivan	Shelbyville	0.015	0.027	0.244	1.803
Tolono	Charleston	0.008	0.015	0.141	1.044
Tuscola	Charleston	0.015	0.026	0.229	1.693
Vandalia	Carlyle	0.018	0.032	0.292	2.164
Villa Grove	Charleston	0.010	0.018	0.161	1.191
Virden	Springfield	0.012	0.024	0.214	1.585
Urbana	Shelbyville	0.072	0.121	1.150	8.514
Total		0.533	0.950	8.681	64.238

Discount Rate: .10
P Reduction Required: 0.9
Al:P Mole Ratio: 2:1
Polymer Cost/Pound: $1.97

Mg/l of P in Influent: 10
Construction Cost Index: 1.22
Wholesale Price Index-Industrial Commodities: 1.62
No. of Gallone/PE: 100
Alum Cost/Pound: $0.0395

C. Phosphorous Concentration in Influent

Notation	mg/l
C1	10
C2	11

D. Sludge Costs

Notation	Costs
D1	Additional costs for dewatering and incineration plus some additional capital cost.
D2	Additional costs for dewatering. No additional costs for incineration or capital.

These alternative assumptions give rise to 36 possible cases, each of which has a different cost associated with it. Table 3 contains those costs identified by the appropriate notation. For example, the notation A2, B1, C2, D2 refers to cost estimates arising when a discount rate of 9%, a mole ratio of aluminum to phosphorus of 1.80:1, a phosphorus concentration of 11 mg/l and only additional dewatering of sludge are used in the COST program.

Estimates could be presented on a "cents per thousand gallons" basis for each combination of assumptions. The program COST 1 was developed to make such calculations and a sample printout from that program follows. Table 4 contains cost estimates for .1 mgd WWTP to 1.0 mgd WWTP (in increments of .1 mgd) and for a 5 mgd WWTP. Only incremental dewatering costs are considered in the sludge costs in this table.

Ferric chloride is commonly used to remove phosphorus, and the costs for a ferric chloride addition were calculated in the same manner as an alum addition. Table 5 is a complete printout of the COST program assuming the use of ferric chloride. Cost estimates using various combinations of assumptions appear in Table 6. Table 7 contains estimates on a cents per thousand gallons basis.

A comparison of Tables 3 and 6 reveals that ferric chloride costs are approximately 80% to 90% of alum costs. In subsequent comparisons

TABLE 3.--Cost of Phosphorus Removal for 36 Treatment Alternatives (Alum)

	Millions of Dollars			
Assumption	Total Cost of Chemicals and Shipping	Total Yearly Cost	Present Value of Costs to Year 2000	Future Value of Cost Accumulated to Year 2000
A1 B1 C1 D1	$0.463	$0.865	$9.20	$46.3
A2 B1 C1 D1	0.463	0.872	8.58	52.4
A3 B1 C1 D1	0.463	0.880	8.04	59.5
A1 B2 C1 D1	0.498	0.900	9.58	48.2
A2 B2 C1 D1	0.498	0.907	8.93	54.6
A3 B2 C1 D1	0.498	0.915	8.36	61.9
A1 B3 C1 D1	0.533	0.934	9.95	50.1
A2 B3 C1 D1	0.533	0.942	9.28	56.7
A3 B3 C1 D1	0.533	0.950	8.68	64.2
A1 B1 C2 D1	0.505	0.907	9.65	48.6
A2 B1 C2 D1	0.505	0.914	9.00	55.0
A3 B1 C2 D1	0.505	0.922	8.42	62.3
A1 B2 C2 D1	0.544	0.945	1.01	50.6
A2 B2 C2 D1	0.544	0.952	9.38	57.3
A3 B2 C2 D1	0.544	0.960	8.78	65.0
A1 B3 C2 D1	0.582	0.983	1.05	52.7
A2 B3 C2 D1	0.582	0.991	9.76	59.6
A3 B3 C2 D1	0.582	0.999	9.13	67.6
A1 B1 C1 D2	0.463	0.649	6.91	34.8
A2 B1 C1 D2	0.463	0.653	6.44	39.3
A3 D1 C1 D2	0.463	0.657	6.01	44.5
A1 B2 C1 D2	0.498	0.683	7.29	36.7
A2 B2 C1 D2	0.498	0.688	6.78	41.4
A3 B2 C1 D2	0.498	0.692	6.34	46.9
A1 B3 C1 D2	0.533	0.718	7.66	38.6
A2 B3 C1 D2	0.533	0.723	7.13	43.5
A3 B3 C1 D2	0.533	0.727	6.66	49.3
A1 B1 C2 D2	0.505	0.690	7.36	37.1
A2 B1 C2 D2	0.505	0.695	6.85	41.9
A3 B1 C2 D2	0.505	0.699	6.40	47.4
A1 B2 C2 D2	0.544	0.729	7.77	39.1
A2 B2 C2 D2	0.544	0.733	7.23	44.2
A3 B2 C2 D2	0.544	0.738	6.75	50.0
A1 B3 C2 D2	0.582	0.767	8.18	41.2
A2 B3 C2 D2	0.582	0.771	7.61	46.5
A3 B3 C2 D2	0.582	0.776	7.11	52.6

TABLE 4.--Cost of Phosphorus Removal vs. Flow (Alum)

	Cost per Thousand Gallons of Flow ($)			
Cost Component	.1 MGD	.2 MGD	.3 MGD	.4 MGD
Chemicals	.086	.086	.056	.086
Capital	.046	.025	.081	.015
Sludge	.024	.024	.024	.024
Total	.156	.135	.128	.124
Cost Component	.5 MGD	.6 MGD	.7 MGD	.8 MGD
Chemicals	.086	.086	.086	.086
Capital	.013		.010	.009
Sludge	.024	.024	.024	.024
Total	.123	.121	.120	.119
Cost Component	.9 MGD	1.0 MGD	5 MGD	
Chemicals	.086	.086	.086	
Capital	.009	.008	.005	
Sludge	.024	.024	.024	
Total	.119	.118	.115	

Discount Rate: .10
P Reduction Required: 0.9
Al:P Mole Ratio: 1:8
Polymer Cost/Pound: $1.97
Mg/l of P in Influent: 10
Construction Cost Index: 1.22
Wholesale Price Index-Industrial Commodities: 1.62
No. of Gallons/PE: 100
Alum Cost/Pound: $0.0395

TABLE 5.--Cost of Phosphorus Removal for One Treatment Alternative (Ferric Chloride)

		(Cost in Millions of Dollars)			
Sewage Treatment Plant	Lake Receiving Discharge	Yearly Chemical Cost	Total Yearly Cost Chemicals, Sludge, Amortized Capital	Present Value of Fugure Expenditures	Future Value of Expenditures in Year 2000
Arcola	Charleston	$0.006	$0.014	$0.122	$0.906
Arthur	Shelbyville	0.006	0.014	0.120	0.890
Auburn	Springfield	0.007	0.016	0.146	1.079
Bement	Shelbyville	0.004	0.011	0.097	0.761
Benld	- - -	0.004	0.011	0.103	0.763
Farmer City	Clinton	0.006	0.014	0.119	0.882
Fisher	Decatur	0.004	0.010	0.096	0.709
Gibson City	Decatur	0.008	0.018	0.156	1.156
Hoopeston	Vermillion	0.016	0.034	0.305	2.257
Leroy	Clinton	0.007	0.016	0.152	1.126
Marion	Crab Orchard	0.003	0.064	0.582	4.306
Monticello	Decatur	0.011	0.023	0.203	1.500
Mt. Vernon	Rend	0.043	0.086	0.778	5.758
Mt. Zion	Decatur	0.006	0.014	0.130	0.962
Pana	Carlyle	0.016	0.033	0.295	2.182
Pawnee	Springfield	0.005	0.012	0.115	0.854
Paxton	Decatur	0.010	0.022	0.191	1.416
Rantoul	Decatur	0.065	0.126	1.196	8.852
Shelbyville	Carlyle	0.013	0.026	0.234	1.733
St. Elmo	Carlyle	0.004	0.011	0.098	0.722
Sullivan	Shelbyville	0.011	0.023	0.204	1.508
Tolono	Charleston	0.005	0.013	0.120	0.891
Vandalia	Carlyle	0.013	0.027	0.246	1.821
Villa Grove	Charleston	0.007	0.016	0.136	1.008
Virden	Springfield	0.009	0.020	0.181	1.342
Urbana	Shelbyville	0.051	0.100	0.951	7.040
Total		0.380	0.796	7.270	53.380

Discount Rate: 0.10
P Reduction Required: 0.9
Fe:P Mole Ratio: 2:1
Mg/l P in Influent: 10

Construction Cost Index: 1.22
Wholesale Price Index for Construction Commodities: 1.62
No. of Gallons/PE: 100
Ferric Chloride Price/Pound: $0.05
Polymer Cost/Pound: $1.97

TABLE 6.--Cost of Phosphorus Removal for 36 Treatment Alternatives (Ferric Chloride)

	Millions of Dollars			
Assumption	Total Cost of Chemicals and Shipping	Total Yearly Cost	Present Value of Costs to Year 2000	Future Value of Cost Accumulated to Year 2000
A1 B1 C1 D1	$0.332	$0.733	$7.79	$39.23
A2 B1 C1 D1	0.332	0.741	7.27	44.49
A3 D1 C1 D1	0.332	0.748	6.83	50.54
A1 B2 C1 D1	0.356	0.757	8.05	40.52
A2 B2 C1 D1	0.356	0.765	7.52	45.94
A3 B2 C1 D1	0.356	0.772	7.05	52.17
A1 B3 C1 D1	0.380	0.781	8.31	41.82
A2 B3 C1 D1	0.380	0.789	7.76	47.39
A3 B3 C1 D1	0.380	0.796	7.27	53.80
A1 B1 C2 D1	0.361	0.762	8.10	40.78
A2 B1 C2 D1	0.361	0.770	7.57	46.23
A3 B1 C2 D1	0.361	0.777	7.09	52.49
A1 B2 C2 D1	0.387	0.788	8.38	42.20
A2 B2 C2 D1	0.387	0.796	7.83	47.82
A3 B2 C2 D1	0.387	0.804	7.34	54.29
A1 B3 C2 D1	0.413	0.815	8.67	43.62
A2 B3 C2 D1	0.413	0.822	8.09	49.42
A3 B3 C2 D1	0.413	0.830	7.58	56.08
A1 B1 C1 D2	0.332	0.517	5.51	27.71
A2 B1 C1 D2	0.332	0.521	5.13	31.36
A3 B1 C1 D2	0.332	0.526	4.81	35.56
A1 B2 C1 D2	0.356	0.541	5.76	29.00
A2 B2 C1 D2	0.356	0.545	5.37	32.81
A3 B2 C1 D2	0.356	0.550	5.03	37.19
A1 B3 C1 D2	0.380	0.565	6.02	30.30
A2 B3 C1 D2	0.380	0.569	5.61	34.26
A3 B3 C1 D2	0.380	0.574	5.25	38.82
A1 B1 C2 D2	0.361	0.546	5.81	29.26
A2 B1 C2 D2	0.361	0.550	5.42	33.10
A3 B1 C2 D2	0.361	0.555	5.07	37.52
A1 B2 C2 D2	0.387	0.572	6.10	30.68
A2 B2 C2 D2	0.387	0.577	5.68	34.70
A3 B2 C2 D2	0.387	0.581	5.31	39.31
A1 B3 C2 D2	0.413	0.599	6.38	32.10
A2 B3 C2 D2	0.413	0.603	5.94	36.29
A3 B3 C2 D2	0.413	0.607	5.55	41.11

TABLE 7.--Cost of Phosphorus Removal vs. Flow (Ferric Chloride)

	Cost per Thousand Gallons of Flow			
Cost Component	.1 MGD	.2 MGD	.3 MGD	.4 MGD
Chemicals	.061	.061	.061	.061
Capital	.046	.025	.018	.015
Sludge	.030	.030	.030	.030
Total	.138	.117	.110	.106
Cost Component	.5 MGD	.6 MGD	.7 MGD	.8 MGD
Chemicals	.061	.061	.061	.061
Capital	.012	.011	.010	.009
Sludge	.030	.030	.030	.030
Total	.104	.103	.102	.101
Cost Component	.9 MGD	1.0 MGD	5 MGD	
Chemicals	.061	.061	.061	
Capital	.009	.008	.004	
Sludge	.030	.030	.030	
Total	.101	.100	.095	

Discount Rate: .10
P Reduction Required: 0.9
Al:P Mole Ratio: 1:8
Polymer Cost/Pound: $1.97
Mg/l of P in influent: 10
Construction Cost Index: 1.22
Wholesale Price Index-Industrial Commodities: 1.62
No. of Gallons/PE: 100
Ferric Chloride/Pound: $0.05

between benefits and costs we use the cost of a ferric chloride addition since it seems to be somewhat less expensive than an alum addition.

Phosphorus Removal by Land Application

Wastewater treatment by land application represents another technique for controlling phosphorous emissions. The three general types of land application systems are irrigation, infiltration-percolation and overland flow. Irrigation is the most widely used method; it generally removes larger amounts of phosphorus than the other two techniques. The expected phosphorous removal is in the 80-99% range (9, p. 7). Other pollutants (BOD and SS and nitrogen) also are removed through an irrigation wastewater treatment process. The cost estimates that follow are exclusively for irrigation wastewater treatment since this technique achieves the best results and costs for certain irrigation techniques are not larger than for other land application methods.

The cost estimates used in this study are based primarily on the USEPA technical report entitled Costs of Wastewater Treatment by Land Application (9). As will be seen, costs of land application are high relative to mineral addition costs. Several cost estimates are presented by considering various combinations of reasonable assumptions. However, our assumptions are on the conservative side in the sense that they lead to cost estimates that are on the low side. Yet, the costs of mineral additions still appear to be lower than land application costs.

An example of land application costs is given below for flows of .25, .5, 1 and 2 mgd. The analysis assumes that:

1. the discount rate is 10% and capital is amortized over 20 years,
2. one mile of piping is required with gravity flow,
3. the irrigation rate is 2.5 in/wk.,
4. storage for 10 weeks is provided,
5. some amount of land leveling is needed,
6. distribution is by surface flooding using border strips and,
7. service roads and fencing are required.

Table 8 breaks out the foregoing costs. Figures in brackets [ ] are unamortized capital costs, and all are on a February, 1973 basis. Unamortized capital costs are in dollars, but other costs are in cents per 1,000 gallons.

TABLE 8.--Cost of Land Treatment vs. Flow

Cost Components		Flows in MGD			
		.25	.5	1	2
1. Land requirement	in acres	45	85	170	330
2. Gravity pipe	1 mile				
Capital		[$85,000]	[$95,000]	[$105,000]	[$120,000]
Amortization		10.95	6.12	3.38	1.93
O & M		.3	.15	.09	.05
3. Storage	for 10 week				
Capital		[$45,000]	[$75,000]	[$120,000]	[$230,000]
Amortization		5.80	4.83	3.86	.35
O & M		.8	.6	.45	.35
4. Leveling	500 cy/acre				
Capital		[$13,000]	[$23,000]	[$40,000]	[$80,000]
Amortization		1.67	1.48	1.29	1.29
5. Distribution					
Capital		[$13,000]	[$20,000]	[$38,000]	[$62,000]
Amortization		1.67	1.29	1.22	1.00
O & M		.10	.08	.06	.05
6. Additional Costs roads and fencing	for service				
Capital		[$30,000]	[$44,000]	[$68,000]	[$100,000]
Amortization		3.86	2.83	2.19	1.61
O & M		.01	.01	.01	.01
7. Total Amortized					
Capital		23.95	16.55	11.94	9.53
Total O & M		1.21	.84	.61	.46
Total		25.16	17.39	12.55	9.99

The above costs become 50% larger when updated to July, 1977 by using the USEPA's Sewer Construction Cost Index, as recommended by our primary reference (9, p. 30). Therefore, the cost of land application, under the assumptions employed in Table 8, are:

Flow	¢/1,000 gal.
.25 MGD	37.74
.5 MGD	26.09
1 MGD	18.83
2 MGD	14.97

The cost of land itself has not been included in these estimates. It is impossible to take a very low estimate for land costs, (say) $1,000 per acre, and assume that the land can be resold after 20 years for its original purchase price of $2,000/acre (9, p. 27). At 10% interest, the present value of $1 twenty years from now is $.1486. Thus, the net price per acre would be $1,000 (1-.1486) = $851 in present value terms. Land costs would be

Flow	Total Cost	¢/1,000 gal.
.25 MGD	(45 ac)($851) = $ 38,295	4.93
.5 MGD	(85 ac)($851) = $ 72,335	4.66
1 MGD	(17 ac)($851) = $144,670	4.66
2 MGD	(330 ac)($851) = $280,830	4.52

Contrary to the primary reference (9, p. 57, 135), it is not correct to subtract net crop revenues from the other costs of wastewater land application. It is, however, correct to treat any increase in the lease or rental value of the land due to wastewater application as a deduction from other estimated costs. With a rate of return on private investment of 10%, land sells for $1,000 if it is able to generate a yearly return of $100 in the form of net crop revenues. Let us make the rather generous assumption that wastewater application raises the return by 50%, i.e., to $150 per annum. In that event, we would say that the return would be made up of two parts: one part is a $100 return to farming and the other part, or $50, is a benefit produced by the land application of wastewater. It is only the latter amount that should be subtracted from other land application costs. The assumption of a 50% increase in land value due to land application implies that cost estimates should be reduced as follows for a plant with a flow of .25 mgd:

$$(\$50/\text{ac.-yr.} \times 45 \text{ ac.} \times 1{,}000¢/1{,}000 \text{ gal.}) \div (250{,}000 \text{ gal.} \times 365 \text{ days/yr.}) = 2.47¢/1{,}000 \text{ gal.}$$

Similarly, for the other plants

.5 mgd: reduction of 2.33 ¢/1,000 gal.
1 mgd: reduction of 2.33 ¢/1,000 gal.
2 mgd: reduction of 2.26 ¢/1,000 gal.

These benefits can be subtracted from land costs to get a new net land cost which is a low estimate because of the small purchase price of the land originally assumed and the generous estimate of the beneficial effect of wastewater application. The net land costs are estimated as:

Flow	Cost
.25 mgd:	2.46 ¢/1,000 gal.
.50 mgd:	2.33 ¢/1,000 gal.
1 mgd:	2.33 ¢/1,000 gal.
2 mgd:	2.26 ¢/1,000 gal.

Finally, the cost of land application is estimated below:

Flow	Cost
.25 mgd:	37.74¢ + 2.46¢ = 40.2 ¢/1,000 gal.
.50 mgd:	26.09¢ + 2.33¢ = 28.42¢/1,000 gal.
1 mgd:	18.83¢ + 2.33¢ = 21.16¢/1,000 gal.
2 mgd:	14.97¢ + 2.26¢ = 17.23¢/1,000 gal.

A rough estimate of the total yearly cost of land application can be derived from the above and the following information: 16 impacted WWTP fall in the .25 MGD range; 7 are in the .5 MGD range; 1 plant has a flow of 1 MGD; and 3 plants are in the 2 MGD range. The yearly cost of land application is calculated by multiplying the number of impacted WWTP in each range by the appropriate cost in cents per 1,000 gallons times number of thousands of gallons in each range times 365 days per year. Such a calculation yields a yearly cost of approximately $1,405,000, which is much higher than the cost of mineral additions. This is not to say that mineral addition is always less costly because there may be a unique set of circumstances that would make land application less costly than a mineral addition for a particular WWTP. On an overall basis, however, mineral additions are cheaper. One additional factor of note is that land application might be viewed as a more complete overall wastewater treatment system than more conventional processes. Undoubtedly, some of the costs of land application should be allocated to control of pollutants other than phosphorus. If such an allocation could be made, costs of land application assigned to phosphorous control would certainly be lower.

These estimates of land application costs depend on several underlying assumptions. Table 9 gives some feel for land application costs with other sets of assumptions. The table is keyed to the following notation:

A. Discount Rate

Notation	Rate
A1	.08
A2	.09
A3	.10

B. Miles of Piping

Notation	Miles
B1	.5
B2	1.0
B3	1.5

C. Service Roads and Fencing

Notation	Assumption
C1	Service Roads and Fencing Included
C2	Service Roads and Fencing Not Included

Other Phosphorus Removal Processes

Phosphorus removal using a two-stage lime addition is another process capable of meeting the proposed 1 mg/l effluent standard. However, due to similar chemical, operating and maintenance costs to the mineral addition processes, but much higher capital and sludge costs, this process was not considered.

A modified lime addition process employing biological control via an anoxic stripping process with lime treatment of a side stream concentrate is a relatively new technique for phosphorus control. The process requires a large capital investment relative to an aluminum or iron addition. However, TABLE 9.--Cost of Land Treatment for 18 Alternatives

Combination of Assumptions	Cents per 1,000 Gallons				Yearly Cost ($)
	.25 MGD	.5 MGD	1 MGD	2 MGD	
A1 B1 C1	27.59	20.64	16.07	13.6	1,022,986
A1 B1 C2	22.55	16.94	13.21	11.49	845,486
A1 B2 C1	34.93	24.73	18.33	14.89	1,218,899
A1 B2 C2	29.89	21.03	15.47	12.78	1,041,400
A1 B3 C1	42.27	28.82	20.60	16.18	1,414,850
A1 B3 C2	37.23	25.12	17.74	14.07	1,237,131
A2 B1 C1	29.67	22.09	17.28	14.65	1,099,289
A2 B1 C2	24.14	18.12	14.21	12.39	907,135
A2 B2 C1	37.52	26.49	19.71	16.05	1,309,638
A2 B2 C2	32.02	22.52	16.64	13.79	1,117,922
A2 B3 C1	45.4	30.89	22.14	17.45	1,520,426
A2 B3 C2	39.9	26.92	19.07	15.19	1,328,710
A3 B1 C1	31.77	23.72	18.56	15.74	1,179,315
A3 B1 C2	25.97	19.46	15.26	13.31	974,952
A3 B2 C1	40.21	28.42	21.16	17.23	1,404,703
A3 B2 C2	34.41	24.16	17.86	14.8	1,200,339
A3 B3 C1	48.65	33.12	23.76	18.72	1,630,090
A3 B3 C2	42.85	28.86	20.46	16.29	1,425,727

yearly chemical costs would be lower for this process than for a metal addition. The following costs come from the company that owns this process.[1]

Cost Components	1 MGD	5 MGD
Capital	$178,500	$493,500
Chemicals (lime)	1,900	9,600
Operating and Maintenance	2,100	3,200

The cost per 1,000 gallons is calculated below at three different discount rates:

Discount Rate	1 MGD	5 MGD
.08	6.1¢	3.5¢
.09	6.5¢	3.7¢
.10	6.8¢	3.9¢

A rough estimate of the cost of this process for a .5 MGD plant would be 7.1¢, 7.6¢, 8¢ for a 8%, 9% and 10% discount rate, respectively.[2] These estimates are between 50% and 60% of the corresponding costs in Tables 4 and 7 for flows of .6 MGD and larger. Thus, the cost of phosphorus control for such plants may be 40% to 50% lower than our previous estimates indicate.

Phosphorus Removal to the .05 mg/l Level

Finally, WWTP effluents currently are subject to the water quality standard of .05 mg/l (Rule 203[c]). This standard clearly is more stringent than the proposed Rule 407(c). The cost of enforcing Rule 203(c) can be estimated from the Ely, Minnesota experience, where the effluent is in the range of .05 mg/l. Costs have been estimated at 91¢/1,000 gallons in 1973-74 dollars distributed as follows (7):

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[1] The actual costs we received were on a 1976 basis and we increased them 5% to put them in 1977 dollars.

[2] These estimates are based on capital costs of $110,000 obtained from a company official. However, no facilities have been designed for flows less than 1 MGD.

1.	Personnel	55.7¢
2.	Chemicals	13.6¢
3.	Utilities	8.8¢
4.	Supplies	5.3¢
5.	Equipment O & R	7.5¢
	Total	90.9¢

Much of the personnel component is due to the requirements for the lake study and only 15% of this category is associated with vacuum filtration of plant sludge operations. Taking only 15% of personnel costs and updating that cost and all others to current dollars, we arrive at a cost estimate of 60.7¢/1,000 gal.[1] By assuming no increase in cost "per thousand gallons" for plants with flows less than the Ely plant, we get a conservative estimate of costs of enforcing Rule 203(c). This figure would be $3,200,000.[2]

Conclusion

Mineral addition is the least costly alternative among commonly used phosphorus removal techniques. The Phostrip process may be less costly but it it not as widely employed. Assuming a 10% rate of discount, the range of annual cost for phosphorus removal by mineral treatment would be from $525,853 (Table 6--ferric chloride addition) to $998,516 (Table 3--alum addition). Enforcing the effluent standard of 0.05 mg/l would cost approximately $3,200,000 per year. Therefore, a benefit of deleting the water quality standard (R76-1) would be a saving in the range of $2.2 to 2.7 million per year.

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[1] Personnel costs were updated by using a factor of 1.256, which is the increase in weekly earnings from December, 1973, to May, 1977. See Monthly Labor Review, May, 1974, p. 110 and July, 1977, p. 77. Chemical costs were increased by a factor of 1.640. See Monthly Labor Review, May, 1974, p. 119 and July, 1977, p. 89. Utilities were increased by 1.502%. Supplies and Equipment Operation and Repairs were adjusted by a factor of 1.416. For the latter adjustment factors, see Monthly Labor Review, May, 1974, p. 119 and July, 1977, p. 89.

[2] Cost calculated by multiplying total flows (in thousands) of impacted plants times 60.7¢ times 365.

It must be emphasized, however, that proposed effluent standard would represent a cost increase ranging from $525,853 to $998,516.

REFERENCES

1. USEPA National Eutrophication Survey, Working Paper Series, Corvallis Environmental Research Laboratory--Corvalis, Oregon and Environmental Monitoring and Support Laboratory--Las Vegas, Nevada.

2. Process Design Manual for Phosphorus Removal, USEPA, April, 1976.

3. A Guide to the Selection of Cost-Effective Wastewater Treatment Systems, USEPA, July, 1975.

4. Engineering News Record, March 24, 1977.

5. Monthly Labor Review, May, 1977. U.S. Department of Labor.

6. Chemical Marketing Reporter, July 11, 1977.

7. Illinois Pollution Control Board Hearings on R-76-1, September 9, 1976, Testimony of Mr. E. F. Barth, Wastwater Research Division, Municipal Environmental Research Laboratory.

8. Wastewater Treatment Processes and Cost Estimating Data, Staff Paper #20, Northeastern Illinois Planning Commission, April, 1977.

9. Cost of Wastewater Treatment by Land Application, USEPA, June, 1975.

10. Illinois Population Projections, Revised 1976, 1970-2025, State of Illinois, Bureau of the Budget.

CHAPTER 3

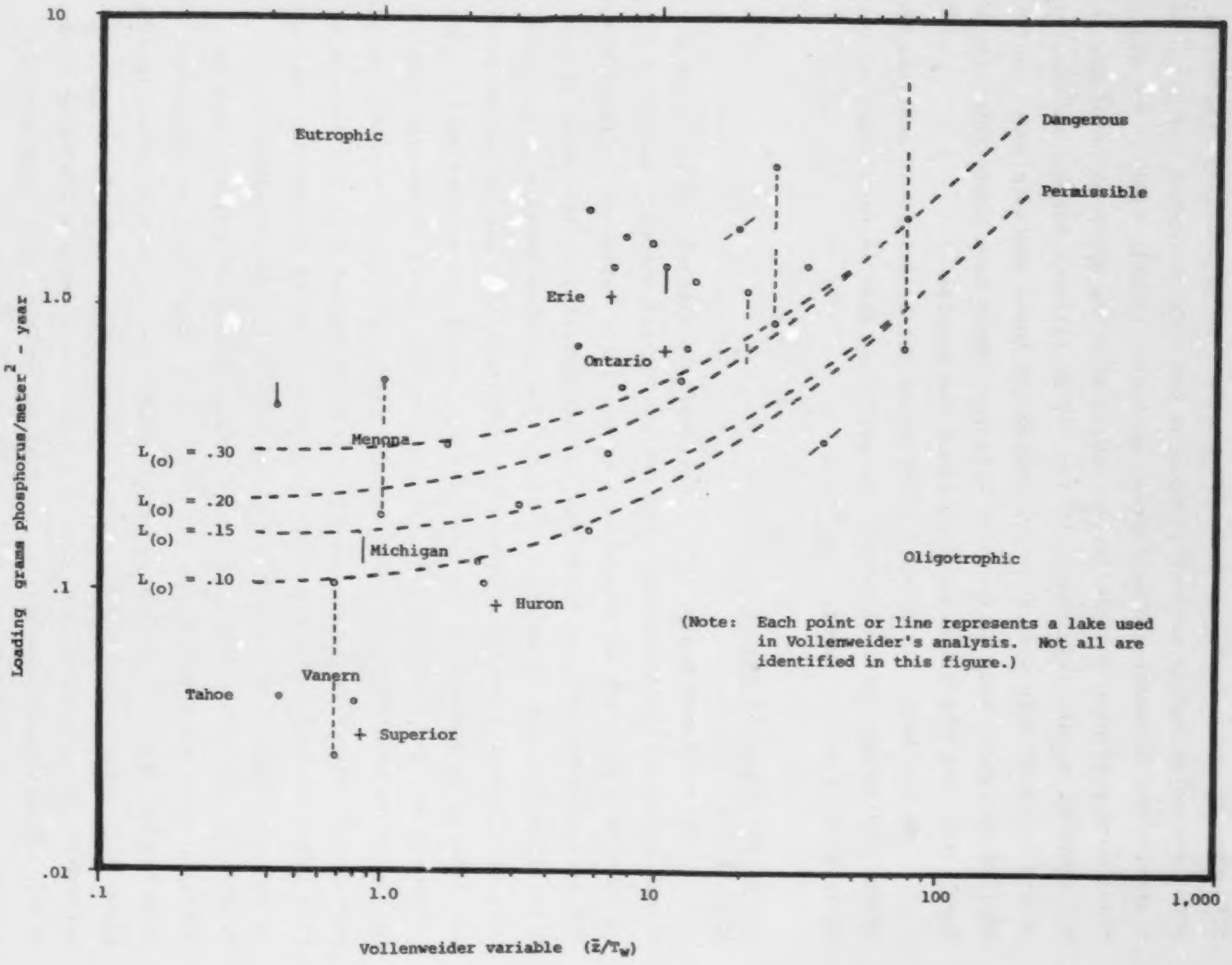
ENVIRONMENTAL IMPACT OF THE PROPOSED PHOSPHORUS REGULATION

The Vollenweider Model

Limnologists have developed a number of mathematical models for use in the study of lake eutrophication (7, 5). Some of these have been designed for the detailed study of one lake or lake type; others are more general and may be applied to a wide range of lakes. Perhaps the most widely utilized model of the latter type has been developed by Vollenweider (3). In their survey of over 800 U.S. lakes and reservoirs undertaken to investigate the increasing eutrophication of freshwater impoundments, the Corvalis Environmental Research Laboratory applied the Vollenweider model in assessing the extent to which nutrient removal is necessary in order to achieve oligotrophic conditions among a wide variety of lakes (1, 2). The Vollenweider model requires a knowledge of the rate at which phosphorus enters a lake, the length of time it takes for water to flush from the lake (or reciprocally, the retention time of the lake), and the lake's mean depth. On the basis of a knowledge of these data, Vollenweider was able to predict the tropic status of a number of lakes having substantially differing limnological characteristics. Fig. 1 illustrates the findings, and the variation in the explanatory variables among the sample lakes. The substantial predictive success of this model, based upon rather modest data requirements, may make it a useful guide to the analysis of Illinois lakes.

As pointed out by the researchers at the Corvalis laboratory, many U.S. lakes differ considerably in their morphometry from the lakes investigated by Vollenweider; in particular, many of them have much shorter retention times. This is especially true of the Illinois lakes included in the Corvalis sample, as well as Illinois lakes in general. Accordingly, the preliminary reports from the Corvalis study sound the warning that conclu-

Fig. 1: Vollenweider's total phosphorus loading vs. mean depth ÷ water residence time ($\bar{z}/T_w$) (3)



sions drawn from the Vollenweider analysis concerning the predicted response of these lakes to reduced nutrient loadings may not be accurate. This warning and a desire to make inferential, or probability statements about the relationship between phosphorus and eutrophication led us to use a statistical technique, discriminant analysis, in this study. The statistical work presented in this chapter deals with the application of the Vollenweider model, illustrated by Fig. 1, to Illinois lakes. We conclude on the basis of this work that Vollenweider's three-variable model can be applied to lakes, such as those in Illinois, which have lower retention times than lakes upon which Vollenweider based his results.

We now turn to a brief discussion of the discriminant analysis technique. Following that, we present an estimated discriminant function and apply it to Illinois lakes.

Use of Discriminant Analysis in Lake Classification

Discriminant analysis is a multivariate statistical technique designed to make classifications into one of several mutually exclusive groups on the basis of a set of independent or predictor variables. Classifications are made in a manner that minimizes the probability, or the cost, of a misclassification. As an example, consider the problem faced by a personnel officer who must classify a prospective employee into one of two groups--(1) "likely to succeed on the job" and (2) "would not perform well." The personnel manager might make his decision on the basis of several characteristics or predictor variables such as years and type of academic training, experience, salary requirements, etc. A discriminant analysis applied to this problem would involve a systematic evaluation of prospective employees so as to minimize the probability of making one of two possible misclassifications: (1) classifying an individual as likely to succeed when he actually would be a failure on the job or (2) classifying an individual as unacceptable when he would have been successful. In this economic impact study discriminant analysis is used in the classification of lakes into eutrophic and oligotrophic groups on the basis of certain predictor variables. This type of classification analysis enables us to evaluate the likely environmental effect of the proposed regulation.

The Corvalis study provided useful data on only 28 Illinois lakes, all of which are eutrophic. In order to enlarge the sample size and provide non-eutrophic lakes for purpose of discrimination, additional lakes were drawn from Ohio, Indiana, Michigan, Minnesota, Wisconsin, New York, and New England. This resulted in a sample of 195 lakes, 35 of which were non-eutrophic. Most of these lakes had mean depth and retention time values similar to Illinois lakes, although a number of them extend beyond the Illinois range. Since many Illinois lakes are artificial impoundments, they are likely to have characteristics affecting their trophic state quite unlike glacier-formed lakes. In particular, lake bottom sediments are likely to discharge nutrients into the water according to different dynamic principles. While many of the lakes in our sample are natural impoundments existing in differing geological settings, nevertheless the lakes of Indiana and Ohio are fairly similar to the Illinois lakes in most important aspects.

Fitting a Discriminant Function to the Vollenweider Model

Several groups of variables in various combinations were tried in an attempt to develop a discriminant function that could distinguish between eutrophic and oligotrophic lakes. As in any statistical work, some decisions were necessary in regard to the theoretical soundness of the models based on the data available for estimating and testing them. We ultimately settled on the three predictor-variables of the Vollenweider model. As mentioned above the model relates the trophic nature of a lake to: (1) the phosphorus loading, (2) the mean depth and (3) the residence time of the water in a lake. The form of the model we employed is:

$$\text{trophic status of lake} = b_0 + b_1 \log P_L + b_2 \log V + b_3 \log V^2$$

where

P_L = phosphorus loading measured in grams per square meter per year.

V = the ratio of a lake's mean depth in meters to the residence time of water in the lake in years (denoted as $\overline{Z}/T_w$ in Fig. 1.)

b_0, b_1, b_2, and b_3 are estimated parameters.

Mesotrophic and oligotrophic lakes are denoted by Group 0 and eutrophic lakes are in Group 1. The estimated discriminant function is:

$$Z_i = .58 + .77 \log P_L - .28 \log V_i - .03(\log V_i)^2.$$

This statistical function is used to establish the location of the Illinois lakes within the zones designated eutrophic, mesotrophic, and oligotrophic in Vollenweider's analytic framework. We see from Fig. 1 that for a given $(\bar{Z}/T_w)$ a lake will be classified within one of these three zones depending on its phosphorus loading rate. It is also evident that any given eutrophic lake will approach closer and closer to this mesotrophic zone as its phosphorus loading is reduced. Even if mesotrophic status is not achieved, the lake has been brought closer to conditions required to achieve non-eutrophic status. In physical terms, we would predict that the lake would show some improvement even if not enough to warrant oligotrophic status. Given the simplicity of the theoretical model, and particularly the neglect of variables which affect the rate of adjustment to be expected of the lake, our predictions will be of a long-run equilibrium nature. Much doubt remains concerning the length of time required for predicted adjustments to take place.

In statistical terms these predictions are subject to appreciable margin of error. While the three zones are depicted graphically in precise terms, it must be recognized that unaccounted-for influences will make the boundaries indistinct. The "mesotrophic category" is itself an attempt to depict a borderline region such that lakes falling within the zone could, with small increases in nutrient loadings, cross over into the eutrophic category. Yet, the lakes in this category are regarded as non-eutrophic, and the classification does not reflect uncertainty in the statistical sense we are considering. We may on this line of reasoning, interpret the movement of a lake in Fig. 1 closer to the mesotrophic boundary as increasing the likelihood that it should be classified mesotrophic.

The process of classifying lakes according to trophic status is, ultimately, a rather elusive one. Vollenweider's analytic framework permits the description of a lake in terms of "productive of too much vegetation," or "not too productive of vegetation." These notions are imprecise and judgmental. When translated into statistical terms, they result in categorical variables rather than the continuous variables usually preferred and most often employed in statistical analysis.

Classifications Made by the Discriminant Function

Table 1 and Fig. 2 show the results of the discriminant analysis of the entire set of sample lakes. The trophic regions determined by Vollenweider (Fig. 1) are reproduced in Fig. 2. Table 1 indicates the degree of success achieved by the discriminant function, employing Vollenweider's variables, in correctly duplicating the classifications made by the Corvalis study group. The significance of the table is that there is a 90% probability of correctly classifying a lake by using discriminant analysis.

TABLE 1.--Classification Table for 195 Lakes Predicted Group Membership by Using Discriminant Analysis

Actual Group Membership	Group 0	Group 1	Totals
Group 0	23	12	35
Group 1	6	154	160
Totals	29	166	195

Percentage of lakes correctly classified:	90.8%
Lakes correctly assigned to Group 0:	79.3%
Lakes correctly assigned to Group 1:	92.8%

The estimated discriminant function is:

$$Z_i = .58 + .77 \ln P_{Li} - .28 \ln V_i - .03(\ln V_i)^2 \qquad i=1, \ldots , 195$$

where the ith lake is assigned to Group 0 (oligotrophic or mesotrophic group) if $Z_i < -1.1$ and to Group 1 (eutrophic group) if $Z > -1.1$. There is a 50% probability that a lake is oligotrophic of $Z = -1.1$. The probability value increases as Z decreases.

Application of Discriminant Function to Illinois Lakes

Having developed a method of applying discriminant analysis to the Vollenweider model, the next step is to repeat the calculations for the 28 Illinois lakes. Table 2 shows the probabilities of correct classification.

Fig. 2.--Trophic Classification of 195 Lakes

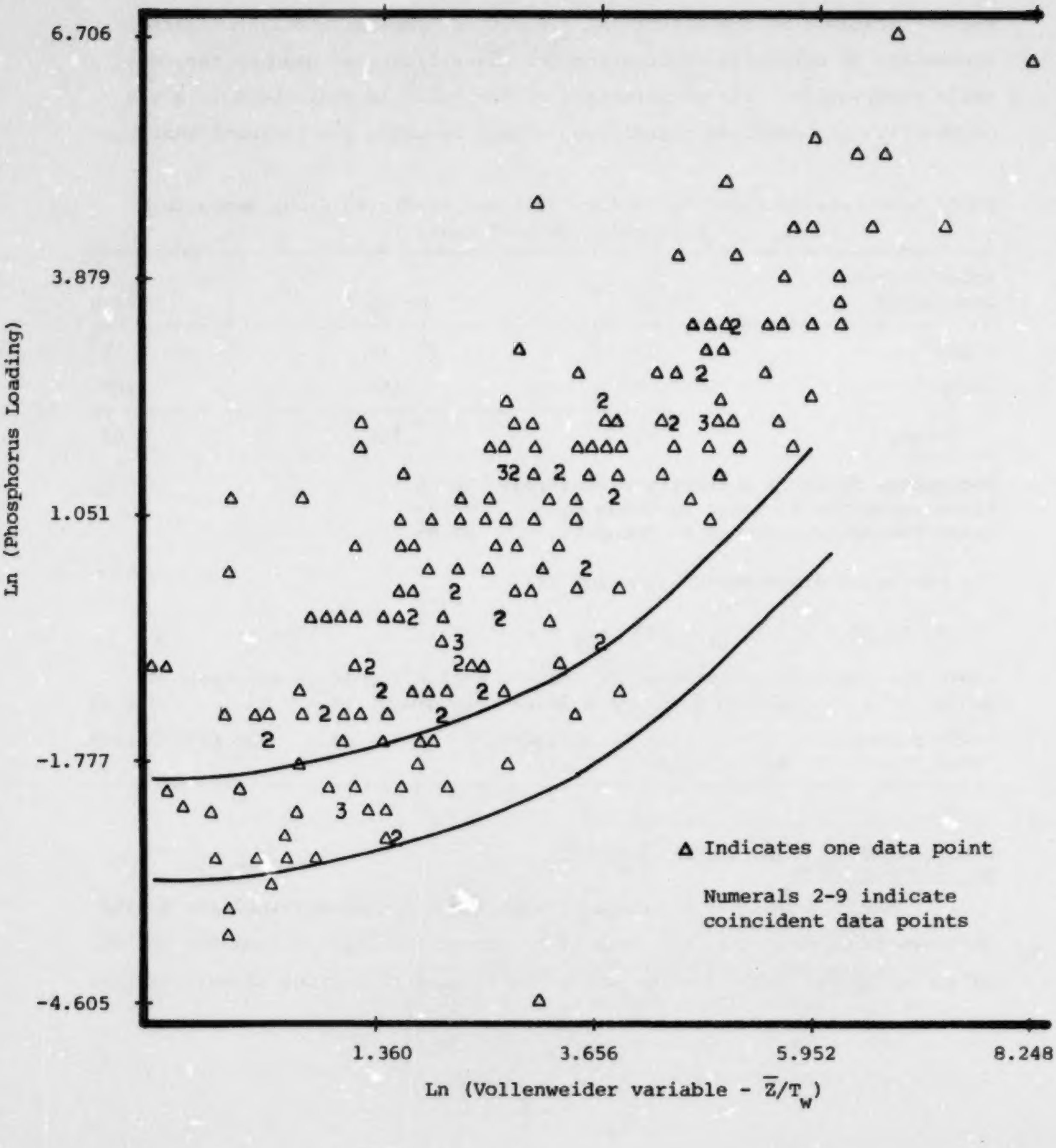


TABLE 2.--Probability of Correctly Identifying the Trophic State of 28 Illinois Lakes

Lake Identification Number	Lake Name	Probability of Group 0 Membership (Oligotrophic)	Probability of Group 1 Membership (Eutrophic)
145	Baldwin	.023	.977
146	Bloomington	.045	.955
147	Carlyle	.021	.979
148	Charleston	.005	.995
149	Crab Orchard	.006	.994
150	Decatur	.009	.991
151	Silver	.011	.989
152	Holiday	.022	.978
153	Horseshoe	.078	.922
154	Long	.0005	.999
155	Lou Yaeger	.012	.988
156	Raccoon	.048	.952
157	Rend	.044	.956
158	Sangchris	.199	.801
159	Slocum	.0004	.999
160	Sprinfield	.032	.967
161	Story	.015	.985
162	Vandalia	.055	.945
163	Vermillion	.010	.990
164	Wematuk	.105	.894
165	Wonder	.002	.998
166	Shelbyville	.010	.989
196	Coffeen	.999	.0005
197	Marie	.005	.995
198	Pistakee	.013	.987
199	Fox	.009	.991
200	Grass	.004	.996
201	Old Ben Mine	.006	.994

In Fig. 3 the same 28 Illinois lakes are plotted along with the 35 non-eutrophic lakes in Vollenweider's trophic zones. All Illinois sample lakes are classified eutrophic by Corvalis and all fall within Vollenweider's eutrophic region. Table 3 gives the corresponding data values for each lake.

The next step in the analysis is to use the discriminant model to predict the responsiveness of the Illinois lakes to reduced phosphorus loadings. A probability level was assumed and phosphorus loadings treated as an unknown (See Appendix 4). By reversing the calculation procedure we may establish predetermined values for the probabilities, and treating the

Fig. 3.--Classification of 28 Illinois Lakes into Trophic Zones

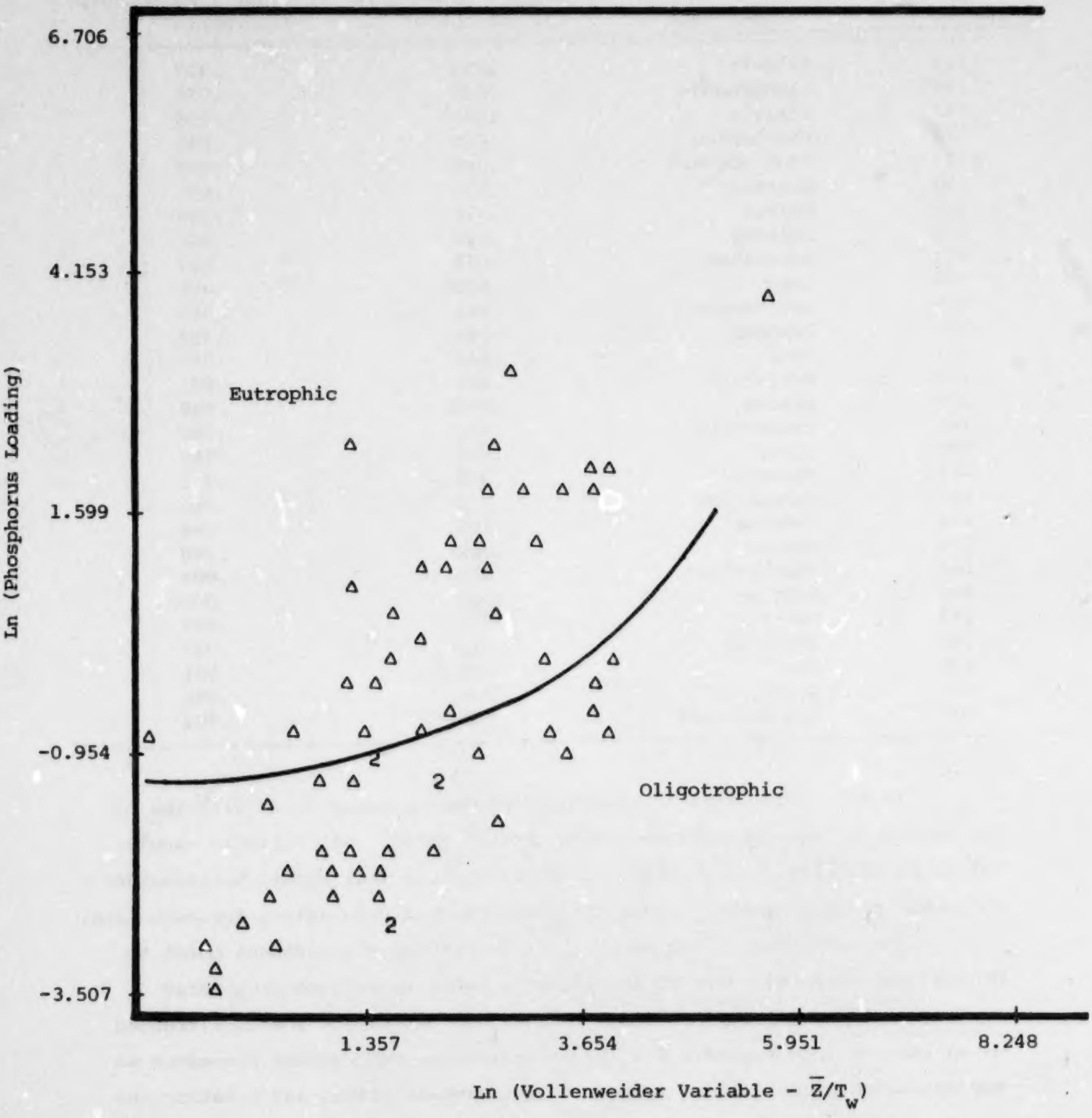


TABLE 3.--Phosphorus Loadings of Lakes Surveyed by Corvalis

Lake Number	Lake Name	Phosphorus Loading $g/m^2/yr$
145	Baldwin	0.58
146	Bloomington	2.17
147	Carlyle	3.01
148	Charleston	52.51
149	Crab Orchard	2.82
150	Decatur	9.15
151	Silver	3.04
152	Holiday	4.03
153	Horseshoe	0.51
154	Long	23.66
155	Lou Yaeger	3.15
156	Raccoon	1.17
157	Rend	0.97
158	Sangchris	0.38
159	Slocum	11.18
160	Springfield	1.70
161	Story	2.18
162	Vandalia	0.96
163	Vermillion	10.20
164	Wematuk	0.61
165	Wonder	12.39
166	Shelbyville	4.12
196	Coffeen	0.01
197	Marie	8.10
198	Pistakee	8.10
199	Fox	8.10
200	Grass	8.10
201	Old Ben Mine	4.50
	Oligotrophic or Mesotrophic Lakes	
9	Long Lake, Maine	0.14
10	Mattawamkeao Lake, Maine	0.59
11	Moosehead Lake, Maine	0.08
12	Rangely Lake, Maine	0.09
13	Sebago Lake, Maine	0.08
15	Long Lake, Maine	0.12
16	Bay of Naples, Maine	0.51
28	Lake Carlevoix, Mich.	0.12
43	Crystal Lake, Mich.	0.07
44	Higgins Lake, Mich.	0.03
57	Green Lake, Minn.	0.09
61	Lake Carlos, Minn.	0.14

TABLE 3.--Continued

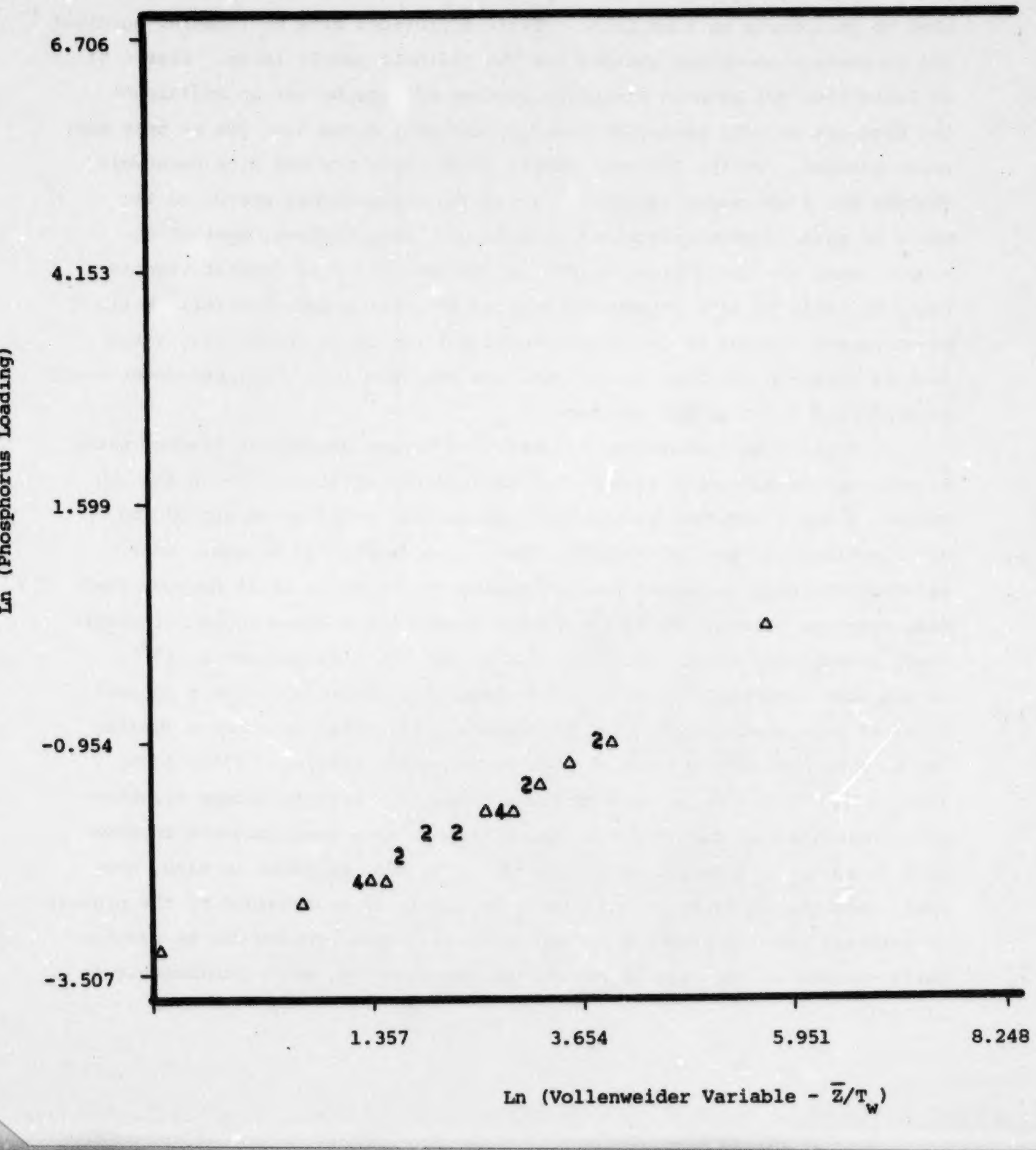
Lake Number	Lake Name	Phosphorus Loading $g/m^2/yr$
	Oligotrophic or Mesotrophic Lakes	
72	Cass Lake, Minn.	0.35
79	Leech Lake, Minn.	0.04
86	Pelican Lake, Minn.	0.06
91	Swan Lake, Minn.	0.47
94	Lake Winnipesaukee, N.H.	0.12
97	Canandaigua Lake, N.Y.	0.14
99	Carry Falls Reservoir, N.Y.	0.71
100	Cayugo Lake, N.Y.	0.49
103	Keuka Lake, N.Y.	0.10
104	Sacandaga Reservoir, N.Y.	0.18
106	Schroon Lake, N.Y.	0.39
107	Seneca Lake, N.Y.	0.38
113	Lake Champlain, Vt.	0.51
115	Harriman Reservoir, Vt.	0.88
118	Waterbury Reservoir, Vt.	1.34
124	Green Lake, Wisc.	0.25
140	Rock Lake, Wisc.	0.05
144	Willow Reservoir, Wisc.	0.47
169	Badger Lake, Minn.	0.34
179	Sacandaga Reservoir, N.Y.	1.10
189	Schroon Lake, N.Y.	0.81
190	Bay of Naples, N.Y.	0.16
191	Lake Winnepesankee, N.H.	0.11

phosphorus loading as unknown, solve for the loading required by the probability value.

Fig. 4 shows the results of calculations in which a .5 probability of non-eutrophic status is established for the 28 Illinois lakes. The corresponding phosphorus loading is then solved for and plotted (in log form) on the vertical axis against log $(\overline{Z}/T_w)$. Comparing Fig. 4 with Fig. 2 shows that when phosphorus loadings in the Illinois lakes are reduced to rates which give them an even chance of becoming non-eutrophic, all the lakes fall within the mesotrophic zone established by Vollenweider.

Comparing Table 4 with Table 3 indicates the extent to which phosphorus loadings must be reduced for a lake to achieve a .5 probability of becoming non-eutrophic.

Fig. 4.--Phosphorus Loadings for 28 Illinois Lakes Which Provide 0.5 Probability for Non-Eutrophic Classification



Available data for the sample Illinois lakes indicate a median non-point contribution of phosphorus of about 86 percent. To the extent that these broad averages apply to the generality of lakes in Illinois, effective control of non-point sources will be required in order to achieve statewide improvement in water quality. On the other hand, it should be possible to achieve some water quality improvement through point source control of phosphorus on some lakes. Table 4 provides data on limiting nutrient and percentage non-point sources for the Illinois sample lakes. Eleven of 28 lakes have 90% or more non-point sources of phosphorus; an additional ten have 60% or more non-point sources; and only three have 30% or less non-point sources. Of the Illinois sample lakes, only Old Ben Mine Reservoir (STORET No. 1765) seems capable of achieving oligotrophic status on the basis of point source control of phosphorus. Nevertheless, most of the sample lakes are phosphorus limited in the production of aquatic vegetation, or could be made phosphorus limited by point source control. While point source control of phosphorus would not result in an entirely satisfactory clean-up of these lakes, nevertheless some long-run improvement could be predicted for a number of them.

Table 4 is essentially a summary of target phosphorus loading rates to achieve non-eutrophic status with minimum probabilities of .50 and .80. Columns 5 and 7 show the phosphorus loading that could be tolerated and still achieve .50 and .80 probabilities of non-eutrophic status. Considering the high non-point source loading in Column 3, it is obvious that even complete elimination of phosphorus from point sources would not enable these probability levels to be achieved. Old Ben Mine Reservoir (1765) is the only exception. Several other lakes have relatively lower proportions of non-point sources, and consequently the total phosphorus loading can be substantially reduced through point-source control: 1754, 1725, 1758, 1751, 1750. While none of these lakes is likely to become oligotrophic, nevertheless they would appear likely to show some long-run improvement in response to point-source control. It must be borne in mind, however, that the recovery of many lakes is likely to be retarded by the process of internal loading from the bottom sediment. This problem may be particularly serious in the case of artificial impoundments, which predominate in Illinois.

TABLE 4.--Comparison of Current Loadings, Non-Point Loadings, and Loadings Required for Improved Tropic Status

(1) Lake No.	(2) Current Loading g/m^2/yr	(3) Proportion Non-Point Source Phosphorus	(4) Limit Nutrient	(5) Loading Consistent with Oligotrophic Status at .5 Probability level g/m^2/yr	(6) P Loading with Complete Elimination of Point Sources (2) x (3)	(7) P Loading Consistent with Oligotrophic Status at .80 Probability level g/m^2/yr
145	0.58	.957	P	.08	.56	.04
146	2.17	.94	P	.44	2.04	.21
147	3.01	.97	P	.41	2.92	.20
148	52.51	.863	P	3.43	45.32	1.67
149	2.82	.658	PN*	.20	1.86	.10
150	9.15	.919	P	.81	8.41	.39
151	3.04	.991	PN	.29	3.01	.14
152	4.03	.45	PN	.56	1.81	.27
153	0.51	.99	P	.14	.50	.07
154	23.66	.127	N	.45	3.00	.22
155	3.15	.945	P	.32	2.98	.16
156	1.17	.97	PN	.25	1.13	.12
157	0.97	.80	P	.19	.78	.09
158	0.38	.93	P	.18	.35	.09
159	11.18	.47	N	.19	5.25	.09
160	1.70	.72	P	.29	1.22	.14
161	2.18	.45	P	.24	.98	.12
162	0.96	.963	P	.22	.92	.11
163	10.20	.688	P	.93	7.02	.45
164	0.61	.906	P	.20	.55	.10
165	12.39	.274	PN	.43	3.39	.21
166	4.12	---	--	.39	---	.19
196	0.01	.68	PN	---	---	---
197	8.1	.864	N	.50	7.00	.25
198	8.1	.864	N	.86	7.00	.42
199	8.1	.864	N	.71	7.00	.35
200	8.1	.864	N	.44	7.00	.21
201	4.5	.005	N	.32	.02	.15

* Phosphorus and nitrogen limited at different times.

Conclusion

Control of point-sources of phosphorus will not significantly raise the probabilities of most Illinois lakes becoming oligotrophic or mesotrophic. Table 4 shows the "target" phosphorus loadings that are consistent with a 50% probability and an 80% probability that lakes would become oligotrophic or mesotrophic. Even complete elimination of phosphorus from point sources would not enable us to achieve these targets as indicated by comparing Columns 5 and 6 of Table 4.

REFERENCES

1. Corvalis Environmental Research Laboratory, A Compendium of Lake and Reservoir Data Collected by the National Eutrophication Survey in the Northeast and North-Central United States, USEPA: National Eutrophication Survey, Working Paper No. 474, November, 1975.

2. Corvalis Environmental Research Laboratory, Working Papers, Various Illinois Lakes, USEPA: National Eutrophication Survey, Working Paper Series.

3. P. J. Dillon (prepared on behalf of R. A. Vollenweider), "The Application of the Phosphorus Loading Concept to Eutrophication Research," National Research Council of Canada: NRC Associate Committee on Scientific Criteria for Environmental Quality, June, 1974.

4. Illinois State Water Survey, Department of Registration and Education, Report of Investigation 31, 54, 56, 58, Urbana, 1962, 1966, 1967.

5. Growth Dynamics in Shagawa Lake, Minnesota, with Comments Concerning Projected Restoration of the Lake," in Modeling the Eutrophication Process, E. J. Middlebrooks, D. H. Falkenborg and T. E. Maloney, eds. Utah State University, Logan, Utah, November, 1973, 15-31.

6. W. J. Roberts, Engineer, Illinois State Water Survey, Urbana.

7. W. J. Snodgrass and C. R. O'Melia, "Predictive Model for Phosphorus in Lakes," Current Research, October, 1975, 9, No. 10, 937-944.

CHAPTER 4

BENEFITS OF PHOSPHORUS REMOVAL

Benefits from the improvement of water quality may be expected to be of two sorts. The first pertains to the improved recreational value of water resources to people from the entire State, and beyond. The second type of benefit relates to increased earnings and employment resulting from increased recreational use of Illinois lakes. This latter benefit is likely to be predominantly local in its impact.

In order to estimate the net benefits of water quality improvement resulting from phosphorus removal, we derive an estimated demand curve for lake recreation based upon the travel cost method of Clawson (1, 2).

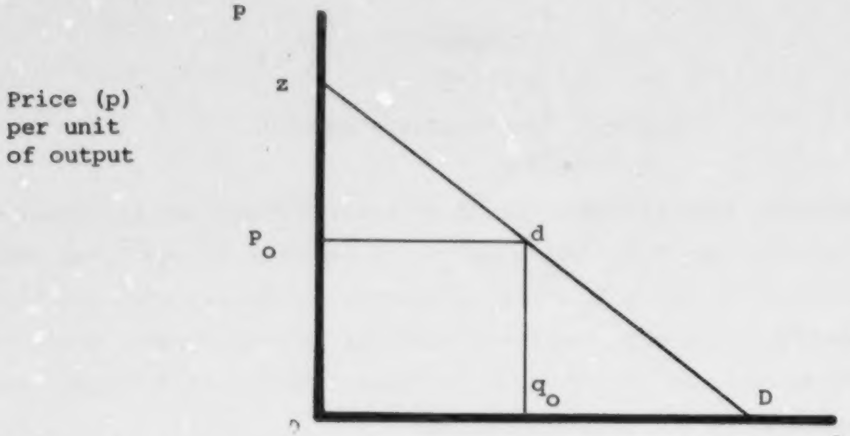
Estimates of impact of phosphorus removal on the Illinois economy are developed from value-added relationships taken from (2) and also derived from the Illinois input-output model.

The Idea of Consumer Surplus

By way of introduction to the analysis of the economic value of improved water quality to recreational users of Illinois lakes, we present a brief discussion of the theory of demand curves and consumer surplus. This is followed by an illustration of how consumer surplus can be estimated by deriving a demand curve for a recreational facility based upon travel cost information.

In economic theory, a demand schedule represents the quantity of a product demanded per unit of time at various hypothetical alternative prices, other things remaining equal.

The illustration following shows a graph of a demand schedule, or demand curve, and a representative currently prevailing price, p_o. At price we see that q_o of the product will be demanded in the market each time period. The area Op_odq_o represents total expenditure.



Product Demand

While Op_odq_o is the amount actually paid by consumers to acquire Oq_o of the product, nevertheless that sum is less than the total amount consumers would be willing to pay to acquire the given amount of product. Maximum willingness to pay is given by $Ozdq_o$. The difference, $p_o$zd, is known as consumer surplus, and is a measure of net benefit derived by consumers when they purchase the product.[1] If the product were available without charge, then OD would be consumed, and the entire area OzD would represent net benefit resulting from the availability of the product.

Suppose that the demand curve in the illustration represented the willingness of people to pay for the recreational use of a lake. Suppose also that there are no user charges. Nevertheless, some users would be willing to pay as much as Oz rather than do without the lake, others would be willing to pay a maximum of, say, Opq, and some would be willing to pay next to nothing. Adding up all of these measures of maximum willingness to pay, we arrive at the sum OzD, which represents the value to the people in in this market (area) of having the lake available for recreational use (i.e. "net benefit" or consumer surplus received by the lake users).

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[1] P_oZd is an approximation to consumer surplus. For a thorough discussion of the subject, see (5).

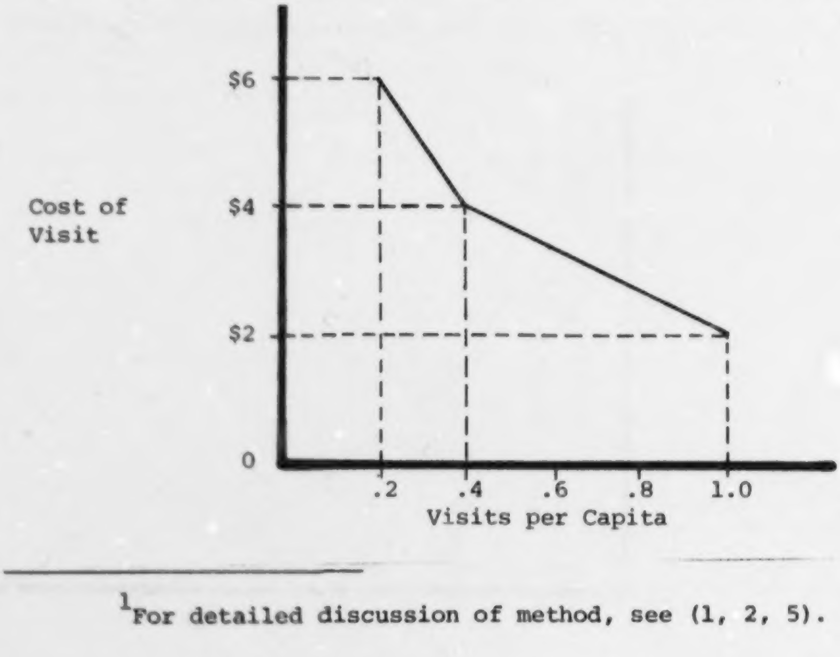
Travel Cost Method of Demand Analysis

It is possible to derive such a demand curve for recreational facilities, such as Illinois lakes. Simple extension of the analysis permits estimates of the benefits to lake users resulting from such things as improved access or improved quality of the facility, such as algae-free water. A simple illustration of the method[1] follows, based upon the work of Clawson (2).

Clawson observes that while recreation facilities are frequently available without charge, nevertheless substantial travel costs must be incurred by consumers. Different visitation rates are observable at different distances. Assuming that different rates are caused only by different travel costs, we are able to infer a schedule of maximum willingness to pay for recreation, or a measure of net benefit.

Suppose that three cities (1, 2, and 3) are located at various distances from a lake. Respective distances are 20, 40, and 60 miles, and travel costs are 10 cents per mile. Populations are 20,000, 40,000, and 60,000, respectively. Annual visits per capita to the lake are observed to be 1, .4, and .2, respectively.

From these data, a demand curve is computed which Clawson refers to



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[1] For detailed discussion of method, see (1, 2, 5).

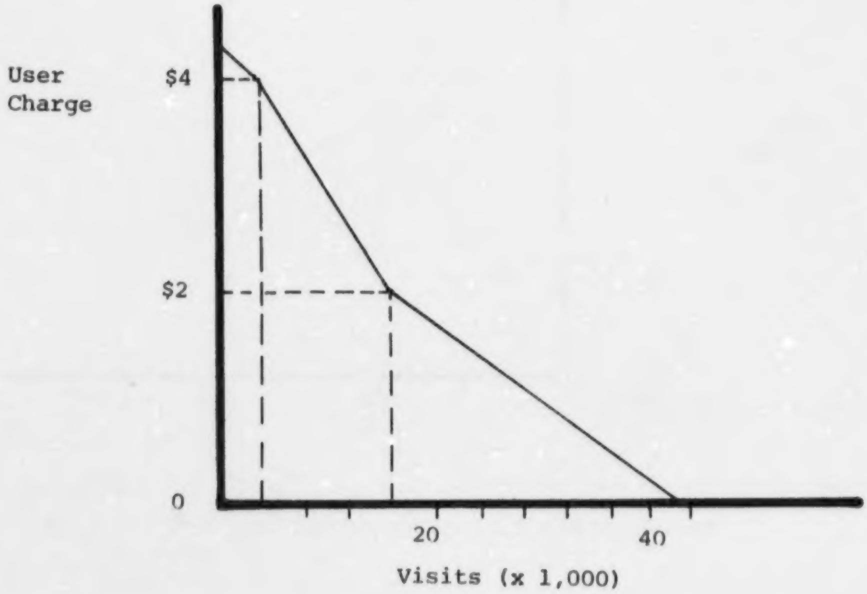
From the demand curve for the total recreation experience, a demand curve for the recreation facility itself can be derived. It is assumed that residents in the various cities differ, in their demand for recreation, only by their distances from the lake. If there is a zero user charge at the lake, then 20,000 visits per year will originate from city 1, 10,000 from city 2, and 12,000 from city 3. This information gives us one point on a demand curve which predicts usage in the market area at various user charges: P = 0, Q = 42,000 visits per year.

For P = \$2, the total cost of visiting the lake from city 1 is \$4: \$2 in travel costs and \$2 in user charge. Also note that the total cost for city 1, with the \$2 user charge, is the same as the cost to city 2 with no user charge. Thus it can be assumed that people from city 1 will visit the lake at a rate of .4 per year. Accordingly, it can be predicted that .4 x 20,000 = 8,000 people will visit the lake from city 1.

Similarly, for city 2, the \$2 user charge yields a total visit cost of \$6, and we predict that .2 x 40,000 = 8,000 people will visit the lake. For city 3, total visit cost is \$8, and we predict no visits with the user charge. The total visits would be 16,000 when P = \$2, and this is a second point on the new demand curve.

Similar reasoning gives us a third point: For P = 4, Q = 4,000 visits. Summarizing these results gives the following schedule and demand curve.

P	Q
0	42,000
2	16,000
4	4,000



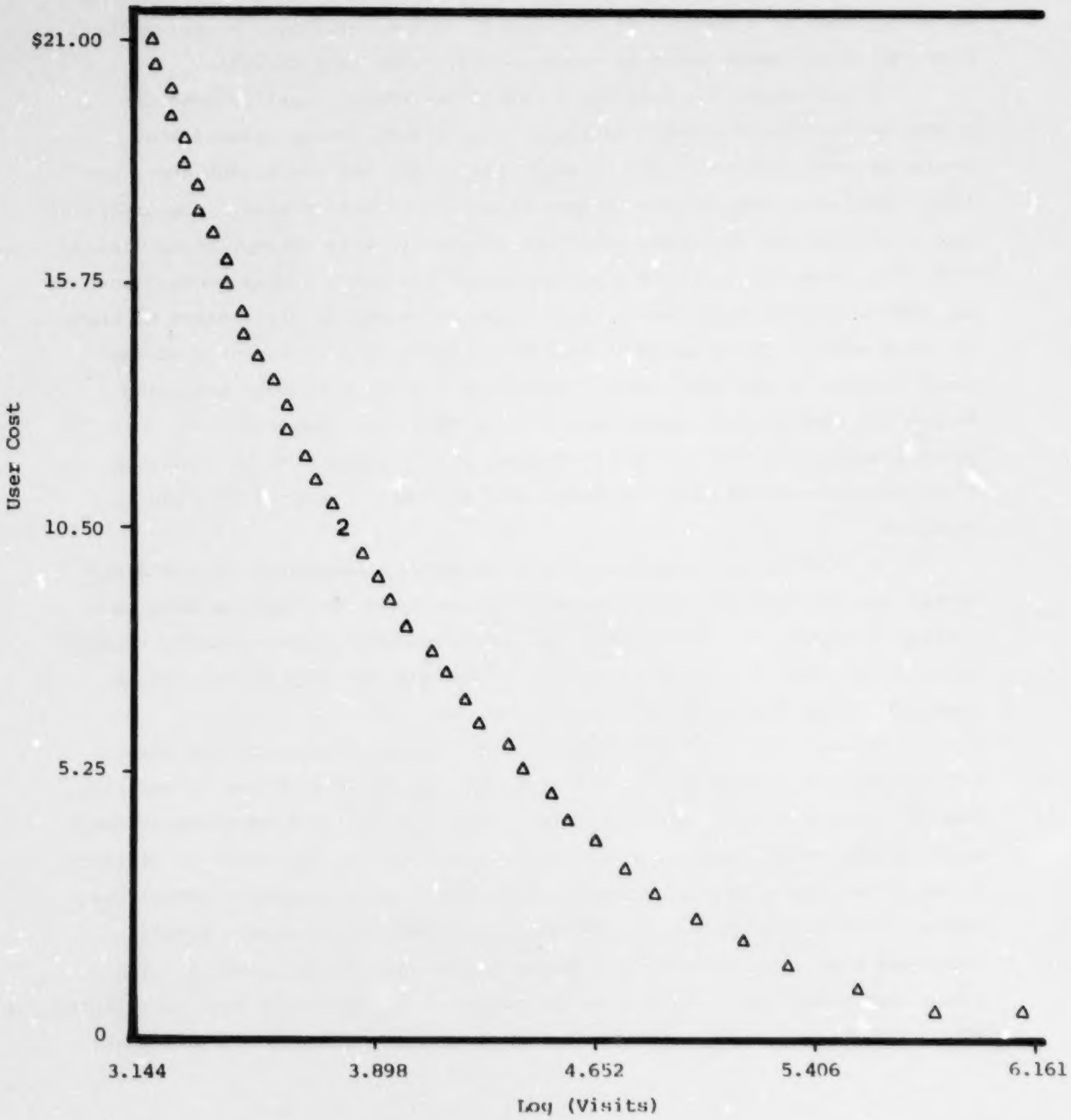
The resulting demand curve, called the demand curve for the resource, predicts the quantity demanded of visits at various prices or user charges per year,other things equal. Of greater interest is the interpretation of maximum willingness to pay for use of the lake for the entire market area; this value is given by the area under the demand curve, and may be interpreted as a measure of the benefit of the facility. A representative empirical demand curve is shown as Fig. 1 for Lake Carlyle.

A word should be said about the "other things equal" clause involved in the demand curve. As already explained, it was assumed that people in each city are alike in their tastes for the recreation area, and differ only with respect to distance from the recreation area. The empirical work which follows will make an effort to satisfy this assumption by dealing with urban areas in Illinois and adjacent to Illinois. Rural populations may well have different tastes, particularly concerning willingness to travel to large lakes. Speaking about Jefferson County, a predominantly agricultural County, it has been said: "A farming community is busy producing during the recreational season and leisure time is nonexistent" (4). It seems likely that, during the off-season, when leisure time is available, different patterns of vacation travel are followed, compared to urban dwellers.

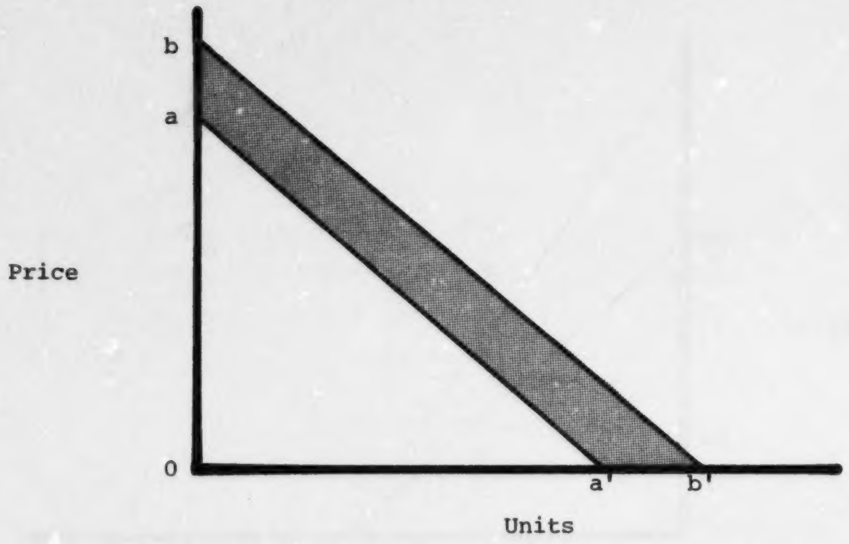
This study will consider only nine large impoundments in the State, partly because they are most similar to those lakes for which we have empirical information. In addition, six of these large lakes actually receive effluent from the dischargers covered by the proposed regulation. These lakes will form the basis for the benefits assessed.

Another aspect of the "other things equal" clause concerns the availability of substitutes, one of the most difficult problems in empirical demand analysis. The Clawson approach deals with the problem of substitutes quite effectively. When data are gathered concerning lake usage by visitors in different distance zones, these data reflect the presence of substitute lakes. Difficult econometric problems are solved directly as a result (although many still remain in complete treatments of the problem). The lakes that enter this analysis may be regarded as reasonably good substitutes for one another in competing for basically the same kind of recreationist.

Fig. 1.--Demand Curve for Lake Carlyle



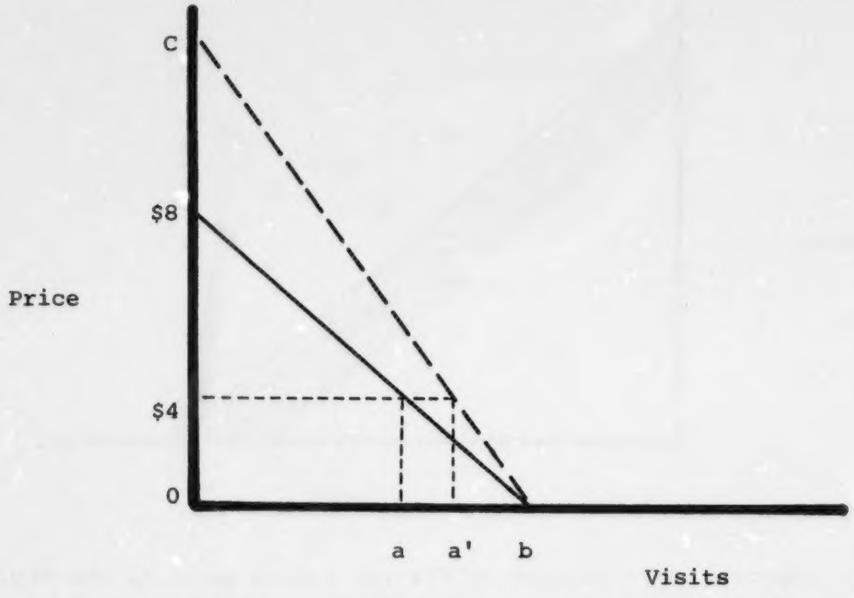
The next problem in this analysis will be to determine how improved water quality will affect the economic value of Illinois lakes. Economic benefits of improved water quality will be reflected in increased net benefit (consumer surplus) to people within the market area of the lakes. Net benefits will be increased in the following fashion:



Improved water quality shifts the demand curve to the right, enlarging net benefit (consumer surplus) by the shaded area. There are several important implications of the diagram. First, among the Oa' visitors using the lake before improvement, each of these visitors enjoys greater net benefit from the lake, reflected in increased maximum willingness to pay for the facility. Secondly, a greater number of visitations, a'b', is expected annually. People are expected to be willing to visit the lake from a greater distance than before improvement, reflected in the increase in maximum willingness to pay for the facility.

There are several reasons why the recreational benefits of the lakes could be understated by the Clawson method of measurement which would tend to underestimate the benefit from water quality improvement. First, when benefits from several substitute sites are measured simultaneously, the observed demand curves lie to the left of the position which would reveal the full benefits of the lakes. Sequential estimation of lake benefits, if they could be introduced one at a time, would correct this problem.

Another source of benefit understatement stems from the fact that travel involves more than simply out-of-pocket expenses. Travel time is such a cost. In the diagram below, the solid demand curve represents net benefits estimated by the travel cost method. The broken line represents net benefits with the cost of travel time included.



Suppose an entrance fee of $4 is imposed at a previously free facility. A reduction of attendance to Oa is predicted. However, people in farther distance zones would not reduce their attendance by the predicted amount, ab, because, for example, a family living in distance zone 1, nearest the lake, might have travel costs four dollars less than families living in zone 2. The user charge would not lower their participation rate to the zone 2 rate because they would still require less time to get to the facility. Thus, overall visit rates would fall by a lesser amount, for example, by a'b.

Another reason why the estimated demand curve understates benefits relates to the greater number of substitutes enjoyed by people living farther from the lake in question, as opposed to those living closer. If money costs increased for visitors in the nearer zones, their visit rates would not fall to that of the more distant group, as assumed in the derivation of the demand curve for the facility (2, pp. 87-88).

Travel Cost Demand Curves for Illinois Lakes

The problem now is to derive empirical estimates of these effects in Illinois, using what data are available, and filling out the picture with inferences. In order to develop lake demand curves, it is necessary to know the distribution of population by distance for each lake. Distance data for each lake have been assembled for 23 largest population centers in and adjacent to Illinois. Illinois Bureau of the Budget estimates for 1975 are used, as well as projections to 2000 (9). Lake use data by recreation category and distance travelled are provided by U.S. Army Corps of Engineers and the Illinois Department of Conservation. Lakes covered by these sources are Carlyle, Shelbyville and Rend. The Department of Conservation also provides data on recreation expenditure at Carlyle Reservoir. County Surface Water Resources, by the Department of Conservation provides information on water quality and lake usage (e.g., 4).

For lakes on which we lack data relating use to distance travelled, use was made of the results obtained by Ullman and Volk (10), based upon Missouri's experience. Ullman and Volk developed a relationship between attendance by Missouri county to eight large impoundments in Missouri and surrounding states. They found that on average attendance fell with the cube of distance, in excess of 40 miles. Their graph can be reproduced by the equation $V = 4.903 - 3 \log d$, where V = visits per capita and d = distance.

The rationale for applying an equation derived from Missouri data to Illinois lakes rests on the assumption that the overall degree of available substitution among recreational facilities is about the same in the two states, and that accessibility to them does not differ markedly. Also, this analysis is restricted to the larger Illinois impoundments, which are of comparable size to the Missouri lakes.

Data and Data Estimation

The first step was to calculate distances of urban areas from major Illinois lakes. Chicago, St. Louis and Quad Cities are defined as metropolitan areas with population in more than one state. Other city names represent either SMSA's or urban places. These cities are taken to represent the urban market area of the lakes. The Fox River Chain of lakes (not covered by this regulatory proposal but included here for purpose of analysis) is treated here as one lake. It is composed of Marie, Grass, Fox and Pistakee Lakes.

Then, predicted annual per capita visitation rates, based on the Ullman and Volk results, were determined. The relationship wherein visit rates decline with the cube of distance is applied for distances of 30 miles or more. For shorter distances, a linear relationship is substituted, with a maximum visitation rate of ten per person per year applied to a distance of one mile.

Lakes Springfield and Decatur are well within 30 miles of large urban areas (Springfield and Decatur, respectively). Accordingly, we have little confidence in our predictions of attendance at these lakes from their close urban neighbors, which dominate the overall prediction. Likewise, the attendance predictions from other, more distant cities to these lakes are suspect. It seems doubtful that people from Chicago, for example, would visit Lake Decatur (in the middle of an urbanized area) at the same rate they would visit an equi-distant lake in a rural setting. However, greater confidence for the predictions concerning the other six lakes seems justified.

Total visitation data are available from the U.S. Army Corps of Engineers for Carlyle, Shelbyville and Rend Lakes. Projections to 1975 for these lakes are 2,320,000, 3,210,000 and 808,000 respectively. Our predictions for urban lake usage are 1,447,390, 1,390,080, and 585,530 respectively. For the three lakes, the ratios of our projections to Army Corps projections are .62, .43, and .72. (If actual 1975 data for Rend Lake are used, the ratio becomes .55.) As a rough estimate we conjecture that about one-half of the visitations to the lake originate in urban areas. (For the Fox Chain the ratio is undoubtedly much larger. Likewise, the "urban lakes," Springfield and Decatur, probably have large proportionate urban contributions.)

Turning to Table 1 we see the results of applying Clawson's method of deriving a demand curve based upon travel cost estimates. As explained earlier, this formulation yields a measure of benefits derived from use of the facility over and above costs of getting there. The results are based on the assumption that variable expense of car operation are the only travel costs involved. (Later, the cost of time will be added to the derivation of the demand curves.)

TABLE 1.--Calculation of a Consumer Surplus for Nine Illinois Lakes Based on Travel Costs

Lake	Total Visits (Millions)	Consumer Surplus (Millions)
Baldwin	3.83	$2.24
Carlyle	1.45	1.32
Crab Orchard	0.51	0.63
Decatur	2.25	1.91
Fox Chain	7.07	4.79
Rend	0.59	0.76
Sangchris	2.09	1.64
Shelbyville	1.39	1.19
Springfield	2.32	1.92
Totals	$21.49	$1.64

Total variable costs are taken to be 5.8 cents per car per mile, for 1976[1] (6). Variable visit costs are derived by multiplying .058 by two to allow for a round trip, per car per visit. (These adjustments are typical of similar studies. Average family size in Illinois is slightly greater than 3.9 persons.) The result is an estimate of .029 dollars per person per mile cost of lake visitation.

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[1] Estimates by (6) for an eight-cylinder Chevelle Malibu, an intermediate car in terms of operation costs.

Total urban net benefit (consumer surplus) derived by users of the 9 lakes, is estimated to be about 27 million dollars per year. If indeed urban visitors are about one-half of the total, then net benefit derived from the presence of these lakes would be about 54 million dollars annually.

Time and Travel Costs

The estimates of net benefit provided up to this point are underestimates because they omit a major component of cost, namely the value of time used up in making the trip. Since time has value in alternative uses, its best alternative use value is the cost of employing time in getting to the recreation site. Two problems immediately arise in connection with lake visitations. The first is, what is the alternative use of time, and its value, that is foregone during travel? Secondly, is the time spent in travel to a lake to be reckoned purely as a cost, or is the act of travel a valuable good in itself to the household?

Addressing the second question first, it is evident that no simple answer exists (7, Chapter 41). For some, much of the pleasure of the entire excursion will be enjoyed getting to the site and back. For others, travel is an annoyance to be endured solely for the use of the site. Still others may be indifferent to the travel experience, in the sense of attaching no utility or disutility to it. For the latter group, foregone alternative uses of time are the only relevant consideration.

We have adopted the assumption that all travellers belong to the third group just discussed, supposing that the other groups more or less cancel out in the aggregate. Indeed, this assumption seems to typify applications of the travel-cost method of demand analysis.

Returning to the first question, what is the value of alternative activity foregone because of travel time to the lakes? It might be argued that the hourly wage is a measure of the value of a person's time. However, there are a number of objections to the use of this measure, the most important being that the alternative to an hour's travel generally is not an hour on the job (7, Chapter 41). More likely time spent travelling to a lake competes with other forms of leisure activity.

In answer to the questions, "which leisure activity, and at what value" we suggest than an hour's travel time competes with an hour at the lake, at the value of one hour's worth of net benefit there. Travel time is estimated as twice the distance to the lake times an average speed of 40 mph, multiplied by the number of visits to a lake.

An hour's worth of net benefit at a lake was estimated as follows: An estimated 80% of visits to intermediate recreational facilities such as the lakes in question are of one day duration (2, p. 67). For a one-day trip this study allocates eight hours of recreation. It was assumed that the remaining 20% of the trips are of two days in duration, the second day providing 12 hours recreation time. On a weighted average basis, we arrive at a typical recreation experience of 10.4 hours per visit. Multiplying total number of visits by 10.4 gives estimated total recreation time for a lake. Division of total net benefit by total recreation time gives estimated net benefit per hour.

The desired result, estimated value of travel time, is found by multiplying net benefit per hour by total travel time to each lake. Addition of these values to the original estimates of net benefit gives the new net benefit estimates, found in Table 2.

TABLE 2.--Calculation of Net Benefit for Nine Illinois Lakes Based on Travel Time

Lake	Total Visits (Millions)	Consumer Surplus (Millions)
Baldwin	$3.83	$2.65
Carlyle	1.45	1.67
Crab Orchard	0.51	0.83
Decatur	2.25	2.26
Fox Chain	7.07	5.70
Rend	0.59	1.01
Sangchris	2.09	2.01
Shelbyville	1.39	1.53
Springfield	2.32	2.28
Totals	$21.49	$1.99

Table 2 summarizes the new estimates of total net benefit derived by people living in the urban market area of the ten Illinois lakes. A comparison with Table 1 gives an indication of the importance of travel time in benefits determination. Before looking at the tables, it is interesting to note that, in net benefit terms, travel cost per person per mile is $.003, on the average (though this varies from lake to lake). At 40 mph this gives $.12 per hour per person or $.48 per hour per car. Total cost per mile, variable cost of car operation plus time cost, rises from $.029 to $.032, on the average, an increase of about 10%. These travel cost figures are low by comparison with the published summary information provided in reference (3, pp. 125-129). There we find travel time evaluated from $.66 to $.76 per hour. These figures are presumably on a per car basis. Another estimate is $.015 per mile per person compared with our $.003. Had the larger figures been used, the measure of net benefits would have increased greatly.

From Table 2 we see that net benefit including time cost is 22% greater than the estimate excluding the value of time. Clearly, net benefit has increased more than proportionately with cost per mile. We find that lakes that are more remote from population centers receive a greater increment of net benefit when time costs are explicitly considered than lakes nearer the cities. Springfield Lake, for example, shows a 19% increase in estimated net benefit; Crab Orchard, more remotely located, shows a 32% increase.

Projections of Net Benefit at Illinois Lakes

Lake net benefits have been estimated for the years 1990 and 2000 to facilitate comparison with costs of this proposed regulation. The projections are given in Tables 3 and 4. The increased are accounted for as follows: First, increased population will result in greater lake usage. State of Illinois population projections were used to account for this source of growth (9). Secondly, the increased pressures of urban living, together with improved opportunities afforded by higher real incomes and increased leisure time, are expected to result in greater value being

TABLE 3.--Projected Net Benefit from Visitation to 9 Illinois Lakes: 1990

Lake	Total Visits (Millions)	Consumer Surplus (Millions $)
Baldwin	6.17	4.29
Carlyle	2.34	2.72
Crab Orchard	0.74	1.34
Decatur	3.08	3.49
Fox Chain	1.20	9.68
Rend	0.95	1.65
Sangchris	3.01	3.24
Shelbyville	2.30	2.55
Springfield	3.11	3.54
Totals	3.37	3.25

TABLE 4.--Total Urban Net Benefit from Visitation to 9 Illinois Lakes: 2000

Lake	Total Visits (Millions)	Consumer Surplus (Millions $)
Baldwin	6.77	4.72
Carlyle	2.57	3.00
Crab Orchard	0.82	1.49
Decatur	3.47	3.91
Fox Chain	13.49	10.85
Rend	1.05	1.83
Sangchris	3.37	3.62
Shelbyville	2.59	2.85
Springfield	3.48	3.95
Totals	37.62	36.21

attached to a lake visit. In other words, the maximum willingness to pay for the use of a lake, or compensating variation, increases over time.

In order to capture the effect of this second influence, we relied on Army Corps of Engineers' projections of visitations at Carlyle, Rend and Shelbyville Lakes. Pertinent data from their reports are given in Table 5.

TABLE 5.--Projected Visitations to Three Illinois Lakes

	Millions		
	1975	1990	2000
Carlyle	2.32	3.22	3.99
Shelbyville	3.21	5.29*	6.52*
Rend	.808	1.344	1.654

*Estimated from Corps of Engineers' data.

Increased population alone cannot account for these projections within our model. By modifying the forecast equation from $V = 4.90 - 3 \log D$ to $V = 5.08 - 3 \log D$, the forecast of urban visitation as a proportion of total visitation remains about the same for the three time periods. The constant term in the equation remains the same for 1990 and 2000. This is a reflection of the judgment of numerous forecasters which holds that use of intermediate recreational facilities will increase rapidly for another decade or so, and then taper off towards the end of the century.

It should be noted that our use of Army Corps projections of attendance have been interpreted as forecasts of demand. This assumption is reasonable to the extent that congestion does not develop at these sites during the time period under consideration.

Assumptions Concerning Costs for Benefits Comparison

Table 6 indicates the lakes receiving municipal effluent from dischargers having flows of greater than 1,500 population equivalents. Projected flows for three years, based upon the Bureau of the Budget population projections, are also given in the table. We are able to make benefit estimations on all of these lakes except Charleston, Clinton and Vermillion.

TABLE 6.--Comparison of Accumulated Costs and Net Benefit for Nine Illinois Lakes

(1) Lake	(2) Treatment Plant	(3) Flow (MGD) 1975	(4) Flow (MGD) 1990	(5) Flow (MGD) 2000	(6) $Mil, Value of Costs Accumulated 1978-2000 at 8%	(7) $Mil, Net Value of Consumer Surplus Accumulated 1990-2000 at 8%
Carlyle	Pana	.64	.67	.70	1.17	
	Shelbyville	.49	.51	.58	.93	
	St. Elmo	.17	.18	.19	.38	
	Vandalia	.51	.57	.58	.98	
					3.46	
Charleston	Arcola	.22	.23	.25	.48	47.064
	Tolono	.20	.23	.27	.47	
	Tuscola	.38	.40	.43	.76	
	Villa Grove	.25	.26	.28	.54	
					2.25	
Clinton	Farmer City	.22	.22	.24	.46	
	Leroy	.27	.31	.36	.60	
					1.06	
Crab Orchard	Marion	1.24	1.34	1.46	2.32	
					2.32	
Decatur	Fisher	.15	.18	.20	.37	23.055
	Gibson City	.32	.32	.34	.61	
	Monticello	.41	.43	.45	.80	
	Mt. Zion	.23	.25	.29	.51	
	Payton	.40	.41	.43	.76	
	Rantoul	2.57	3.00	3.39	4.82	
					7.87	
Rend	Mt. Vernon	1.74	1.81	2.05	3.12	60.327
					3.12	
Shelbyville	Arthur	.22	.23	.24	.47	28.614
	Bement	.16	.17	.18	.38	
	Sullivan	.40	.42	.45	.81	
	Urbana	2.01	2.32	2.65	3.82	
					5.48	
Springfield	Auburn	.27	.31	.35	.58	44.180
	Pawnee	.20	.23	.26	.46	
	Virden	.36	.40	.43	.72	
					1.76	
Vermillion	Hoopeston	.66	.70	.72	1.21	61.620
Totals		14.89	16.311	17.99	28.53	264.86

Thus, our estimates of benefit-cost relationships will pertain directly to about 86% of lakes and dischargers affected by the proposed regulation. It should be emphasized that Column 7 of the table, Net Value of Lakes, Accumulated 1990 to 2000, refers to estimates of net value received by metropolitan and other larger city visitors to the lakes. It does not describe estimated benefits of the proposed regulation; rather, it provides the basis for these estimates.

Column 6 of Table 6 gives total cost estimates for 1978 to 2000, accumulated to the year 2000 for meeting the proposed standard of 1.0 mg/l (R76-1). These estimates are the most reasonable lower-bound estimates we feel justified in offering. The 8% discount rate, which is at the lower end of the 8-10% range that we have chosen, favors the benefits estimate. The reason is that, having assumed a delay in the appearance of benefits, the overall benefits stream is displaced farther into the future than the stream of costs, which is assumed to begin at present (1978).

Costs shown in Table 6 are based on the assumption of a Fe:P mole ratio of 1.95 to 1, which is a rather moderate application of $Fe\ Cl_3$ to achieve the proposed effluent standard. Accordingly, the estimated cost of chemical addition is somewhat on a low side.

Lastly, the cost estimates make the most generous plausible assumptions about the cost of sludge disposal. Specifically, we have allowed for costs of dewatering the increased sludge resulting from phosphorus control, but have included in Table 6 estimates for no additional costs for capital equipment, incineration, or sludge removal. Figures are taken from Table 6 of Chapter 2: Assumptions A1 B2 C1 D2.

Table 7 displays data and results of the discriminant analysis, suggesting the progress to be expected towards achieving non-eutrophic status for the six lakes by enforcing the proposed regulation.

In no case do we predict that meeting the proposed effluent standard would cause any of the six lakes to achieve non-eutrophic status. Comparison of Column 4 with Column 8 provides the explanation. Column 4 shows the loadings that would result with enforcement of the proposed regulation; Column 8 gives the loadings required to achieve non-eutrophic status with the modest probability of .5, as predicted from the discriminant function.

TABLE 7.--Comparison of Current Loadings, Reduced Loadings and Probabilities for Improved Trophic Status

	(1) Current Total Loading $g/m^2/yr$	(2) Proportion Point-Source Phosphorus	(3) Reduction in Loading Required by R76-1 $g/m^2/yr$	(4) Loading with R76-1 in Force $g/m^2/yr$ Col. 1-Col. 3	(5) R76-1 Required Net Reduction in Total Lake Loading $g/m^2/yr$ Col. 1/Col. 3	(6) Probability of Non-Eutrophic Classification Under Existing Loadings	(7) Probability of Non-Eutrophic Classification Under R76-1	(8) Loading Required to Achieve Non-Eutrophic Classification with Prob = .5 $g/m^2/yr$
Carlyle	3.01	3%	.171	2.839	5.7%*	.053	.060	.408
Crab Orchard	2.82	34.2%	.441	2.379	15.6%	.009	.013	.196
Decatur	9.15	8.1%	3.73	5.42	40.8%*	.024	.075	.811
Springfield	1.17	28%	.47	.70	27.6%	.110	.281	.246
Shelbyville	4.12	21%	.65	3.47	15.7%	.023	.034	.385
Rend	.97	20.3%	.25	.72	26%	.090	.162	.195

* Exceeds total contribution of point sources reported by USEPA (Corvalis). IEPA has identified additional point sources not reported by Corvalis.

Column 2 states the percentage of point source contributions to each of the lakes, as reported by the USEPA. In view of the large proportion of non-point source phosphorus contributed to these lakes, it is evident that even complete elimination of phosphorus from point sources would not produce non-eutrophic status for the lakes at the 50% prediction level. Nevertheless, as the USEPA points out in the National Eutrophication Survey, phosphorus is the limiting nutrient, at least part of the time, in each of these lakes. As a result, any reduction of phosphorus would be expected to produce some improvement in water quality. A comparison of Columns 6 and 7 of Table 7 gives an impression of expected improvement that must be interpreted with caution. These figures, derived from the discriminant function, show the increase in the probability of the lakes being classified non-eutrophic as a result of the proposed regulation. While increases in the probabilities are fairly substantial, still, the probability levels remain very low. However, even though the lakes will remain substantially overnourished after R76-1, and hence very likely to retain their eutrophic classification, nevertheless an eventual improvement is an entirely reasonable expectation.

It is possible that this method of analysis underestimates the potential effectiveness of point-source control. The relatively small phosphorus contributions by point sources (Col. 2, Table 7) conceal the fact that municipal effluent contains a much higher proportion of available phosphorus than, for example, agricultural runoff. Removal of a pound of phosphorus from municipal effluent would have about the same effect on water quality as two pounds removed from non-point sources.

Table 8 gives ratios of dissolved to total phosphorus for municipal effluents. Table 9 shows similar ratios for streams not subject to the influence of municipal effluent. The ratio of dissolved to total phosphorus is about twice as large in streams receiving municipal effluents than it is in other streams. Therefore, removal of phosphorus from municipal sewage yields a larger environmental benefit than removal of the same amount of phosphorus from, say, agricultural runoff.

Having addressed the question of how much improvement in water quality may be expected from the proposed regulation, the next question is:

TABLE 8.--Mean Dissolved Phosphorus in Treated Effluents

	Town	Range, mg/l	*DP/TP
1.	Richmond	3.6-9.6	0.69
2.	Woodstock	3.9-7.2	0.78
3.	Lake Villa	3.0-7.1	0.72
4.	Round Lake	2.0-7.8	0.81
5.	Antioch	3.4-7.2	0.79
6.	Fox Lake	3.7-6.9	0.72
7.	Mt. Vernon	2.6-10.0	0.79
8.	Gibson City	---	0.73
9.	Fisher	---	0.70
10.	Mt. Zion	---	0.89
11.	Rantoul, W	---	0.86
12.	Monticello	---	0.94
		Mean	.78
		Std. dev.	.079

Conclusion: On the average about 78 percent of total phosphorus in treated domestic waste is in the dissolved form.

* DP = dissolved P
TP = total P

Source: Illinois State Water Survey.

TABLE 9.--Mean Dissolved Phosphorus in Streams

	Stream	Concentration, mg/l	*DP/TP
1.	Rayse Creek	0.05	0.36
2.	Bigg Muddy River (upper)	0.03	0.21
3.	Gun Creek	0.03	0.27
4.	Atchison Creek	0.03	0.33
5.	Lily Lake Drain	0.05	0.50
6.	Sangamon River	0.07	0.18
7.	Fox River (upper)	0.11	0.46
8.	Nippersink Creek	0.16	0.46

* DP = dissolved P
TP = total P

Source: Illinois State Water Survey.

how much increase in recreational value would occur at the lakes for any given amount of water quality improvement? We have no basis for answering this question in quantitative terms. There is, however, qualitative data on the experience at Shagawa Lake in Ely, Minnesota, where point-source phosphorus concentrations in municipal effluent have been reduced to .05 mg per liter through a research-demonstration project by the USEPA. Shagawa Lake has been recovering more slowly than initially expected, although it was reported that there has been a perceptible increase in the recreational use of the lake, even though very clean alternative lakes are available nearby (phone conversations with EPA and Chamber of Commerce at Ely).

The Regulation in Context of Additional Measures

Summarizing our discussion of benefits, it is our conclusion that the proposed regulation is not economically efficient when viewed as a single isolated measure. Viewing it as only one component in a series of steps to enhance water quality, it could prove to be more efficient. In conjunction with control of non-point sources, substantial water quality improvement might be expected. In the future, more will be known about the aging process of lakes. As such information is gathered, the external modification of lakes through nutrient control will perhaps be augmented by measures applied directly to the lakes themselves. The cost-effectiveness of such measures will undoubtedly be influenced favorably by prior application of point-source control. Thus, R76-1 will create a kind of "option value," whose magnitude cannot be measured at this time.

The results do permit some comment on one aspect of option value created by point-source control of phosphorus. We know also that benefits are likely to be delayed for a long period of time, because of internal loading of phosphorus from the sediment; the delay might range from 10 to 30 years in some lakes, although this appears to be a matter of speculation. Indeed, the delay of benefits, compared with costs which begin immediately, is a factor which augments costs relative to benefits.

It appears likely that much of the benefit received from measures to improve water quality will accrue to future generations. The excess of costs over benefits accruing to the present generation can be measured against the willingness of the present generation to pay for benefits to be enjoyed by people in the future. This expresses Mishan's notion of a "posterity fund." For example, if $1.00 invested by generation 1 would yield $2.00 in benefits to generation 2, and if each of 10 people of the present generation would be willing to pay 10 cents to create $2.00 in benefits for posterity, then a project yielding $2.00 in future benefits would be justified on cost-benefit grounds.

In Table 10 we present a summary of the benefit figures of Table 12 recomputed in present value (1979) terms. Yearly costs of $541,124, derived on the conservative assumptions already outlined (see Chapter 2, assumptions A1 B2 C1 D2), are assumed to exist in perpetuity. With a discount rate of 8% the present value of costs is $6,764,050. This figure represents a total amount for all discharges impacted by the proposed regulation. $5,589,000 is the portion of the estimate associated with lakes for which we have estimated consumer surplus in Table 12. The estimated net benefit of $264,860,000 in Table 12 accrues to urban lake users. Net benefit would be twice as large when non-urban consumers are included in the calculation, yielding a total net benefit of $529,720,000 accumulated to year 2000. The present value of this amount is $105,232,000. Assume that between 1990 and 2000 R76-1 benefits equal 1% of the total present net value of the lakes during this period, or $1,053,300.

TABLE 10.--Benefit Figures Recomputed in Present Value (1979) Terms

Present Value of Costs in Perpetuity, Discounted at 8%	Total Present Net Value of Lakes 1990-2000, Discounted at 8%	Hypothetical Present Value of R76-1, 1979-200 Discounted at 8%
$5,589,000	$105,232,000	$1,052,000

We might suppose that the current generation is willing to make a sacrifice of resources on behalf of future generations. The question arises, how much benefit accruing to future generations (after 2000) would the present generation require in order to part with $4,537,000?

Suppose, very conservatively, that our benefit estimates for the year 2000 represent the yearly value each year thereafter. For the six lakes under consideration, this amounts to $17,027,000. Multiplying by 2 to get an estimate of benefits for the entire market area gives a value of $34,054,000 per year from 2000.

We can solve for the rate of increment in per capita benefit required after 2000 to justify the regulation. Letting X equal the required proportional increment in total lake benefit resulting from R76-1 at the six lakes we have

$$\frac{(34{,}054{,}000)\ X}{(.08)(1.08^{21})} = \$4{,}537{,}000$$

$$X = .053.$$

We conclude that if R76-1 can provide a 1% benefit from 1990 to 2000 and 5.3% thereafter, or some equivalent combination of benefits, that the benefits would be approximately equal to costs.

Conclusion

We conclude that the proposed regulation would generate benefits approximately equal to costs if it caused a 1% increase in lake net benefit between 1990 and 2000 and a 5.3% increase in net benefit thereafter. We do not know if this will happen but it gives an idea of what must occur in order for the proposed regulation to be economically efficient.

REFERENCES

1. Marion Clawson, "Methods of Measuring the Demand for and Value of Outdoor Recreation," Resources for the Future, Reprint No. 10, February, 1959.

2. Marion Clawson and Jack L. Knetsch, Economics of Outdoor Recreation, Baltimore: Johns Hopkins Press, 1966.

3. John F. Dwyer and John R. Kelly, Guidelines for Valuation of Water-Based Recreation: Working Draft #2, Urbana: Water Resources Center, University of Illinois, November, 1976.

4. Raymond E. Fisher, *Jefferson County Surface Water Resources*, Illinois Department of Conservation: Division of Fisheries, February, 1971.

5. Arnold Harberger, *Project Evaluation*, London: Macmillan, 1972.

6. John V. Krutilla and Anthony C. Fisher, *The Economics of Natural Environments*, Resources for the Future, 1975.

7. E. J. Mishan, *Cost-Benefit Analysis*, 2nd ed., New York: Praeger, 1976.

8. Runzheimer and Co., for the American Automobile Association, in Sidney Margolius, "Car, Utility Costs Getting Even Worse: Some Savers," *Evergreen*, July 27, 1977, Chicago: Hyde Park Cooperative Society, Inc.

9. State of Illinois Bureau of the Budget, *Illinois Population Projections*: 1970-2025. Revised, 1976. State of Illinois, July, 1976.

10. Edward Ullman and Donald Volk, "An Operational Model for Predicting Reservoir Attendance and Benefits: Implications of a Location Approach to Water Reservation," *Papers of the Michigan Academy of Science, Arts, and Letters*, 47, 1962.

CHAPTER 5

SECONDARY IMPACTS ON THE ILLINOIS ECONOMY

Primary vs. Secondary Impact

> The economic effects on values of outdoor recreation are . . . two kinds. . . . A failure to separate them can result in a confused discussion, improper recognition of relevant and legitimate economic interests, and inferior planning and policy choices.
>
> One class of values includes primary benefits, largely expressed as the willingness to pay on the part of consumers of recreation services. Those who use the recreation opportunity receive a direct benefit whose value is largely measured by their willingness to spend income. These values may or may not register in the commerce of the region or even the commerce of the nation, but this does not make them any less real. . . . These are values that, when appropriately measured, provide the basis for calculating the economic worth of natural resources when used for outdoor recreation.
>
> A second class of benefits includes the gains in the area where the expenditures are made. What is expense to the recreationist is income to the supplier of his goods and services. This is particularly the case for travel, equipment, lodging expenses and other items paid for by the recreationist. Although the recreation opportunity is generally not marketed as such, there are substantial commercial impact effects from the expenditures necessarily involved in use of the available areas. (1, p. 231.)

In this passage, Clawson and Knetch make a clear and important distinction between "primary" benefits, which must be estimated in order to determine whether investment projects costs are economically justified, and secondary or "impact" benefits, which decision makers "are likely also to consider, to some extent: the regional or geographic impact of the park" (1, p. 231). In the last chapter we provided an estimate of the primary benefits of the proposed phosphorus regulation, the appropriate benefits to weigh against the costs of the regulation. In this chapter we estimate the secondary benefits, pertaining to the income and employment-generating aspects of the proposed regulation.

The Impact Process

A process by which secondary benefits are generated can be illustrated by way of example. Suppose that improved water quality results in increased willingness to pay for the use of a lake, as measured by the travel cost method. The expenditures resulting from increased lake usage will increase income and employment flows. Some of these flows will occur in the locality of the lake; some will occur at distinct areas of the state, where visitations originate; some will be generated outside the state. The first two flows are of interest in this chapter.

The expenditures may be viewed as injections into the local and state economy. The difference between expenditures and resulting income and employment flows may be viewed as leakages from the Illinois economy. Each dollar spent on recreation activity will generate succeeding rounds of expenditure, part of which generates income and employment in the locality and the state, and part having its impact elsewhere through leakages outside the state.

Take the example of $10 worth of groceries purchased near the lake. Five dollars worth of income in the form of wages, rent, interest and profit might be generated locally in marketing the product. The other $5 would then represent purchases from outside the market area, where the productive activity generated the income.

To the initial value added locally, worth $5, we must add income generated by succeeding rounds of expenditure. Suppose that 40% of income generated on the first round ($2) is spent locally, the other 60% ($3) spent elsewhere. Of the $2 of locally induced expenditure, suppose that 60% ($1.20) results in value added locally. Second round expenditure, therefore, will have generated an additional $1.20 in income. Succeeding rounds of expenditure will generate income locally--at a diminishing rate because of leakages.

The resulting addition to income will be given by the following "multiplier."

$$k = A \frac{1}{1 - BC} = .5 \frac{1}{1-(.4)(.6)} = .658$$

Thus, the $10 spent on groceries near the lake generates $10 X .658 = $6.58 in income locally. Corresponding to this flow of productivity will be a flow of employment of labor and other resources.

Estimates of Local Impact

The proposed regulation would cause secondary effects throughout the state and more important effects on communities located near impacted lakes. An estimate of recreation expenditures is required for measuring these secondary effects. In the case of state-wide effects we are interested in recreation expenditures made anywhere within Illinois, and for local secondary effects we work with expenditures made within communities near lake recreation sites. Table 1 contains estimates of both state-wide and local expenditures. We took, as our starting point, the value of \$6.30 as an average recreation day expenditure in 1970 prices (2, p. 9). The composition of this figure is given in Column 1 of Table 1 (2, p. 45; 1, p. 236). Column 1 dollars are updated to 1975 by using Implicit Price Deflators for Personal Consumption Expenditures (3, p. 62). Updated expenditures are in Column 2. In Column 3, we multiply Column 2 by the estimated number of urban visits which yields total expenditures for recreation associated with the six lakes for which we estimated benefits. An allowance for automobile depreciation also appears in Column 3; this estimate is based on a cost of \$2.50 per visit in 1960 prices, updated to 1975 (3, p. 236). Estimates in Column 4 are those of Column 3 adjusted for expenditures occurring outside Illinois. Let us devote the percentage of expenditures made at, or on-route to a lake by the symbol p; and let α denote the percentage of out-of-state visitors to Illinois lakes. The estimates in Column 4 are calculated by using the formula:

$$(1 - \alpha) \times (\text{column 3 estimates}) + p\,\alpha\,(\text{Column 3 estimates})$$

where we have determined α to be approximately .30 and p to vary according to each expenditure category (1, p. 237). The figures in Column 4 are estimates of expenditures made within Illinois. Finally, Column 5 contains estimates of expenditures in the communities near the lakes, themselves. We arrive at these estimates by multiplying the numbers in Column 4 by the percentage of expenditures made at, or near, reactional sites (1, p. 237).

If we double the total of Column 5 to adjust for non-urban visitors to lakes we get total local expenditures of approximately \$37.6 million. If this figure increases by 1% due to the proposed regulation, then additional local expenditures would be \$376,000. We assume a local income

TABLE 1.--Estimate of Recreational Expenditures (see text)

	1	2	3*	4*	5*
Food					
off-premise consumption	$ .441	$ .676	$ 5.753	$ 4.307	$ .431
purchased meals and beverages	.447	.615	5.234	5.234	3.402
Lodging	.233	.314	2.669	2.669	1.601
Transportation					
gas and oil	.624	1.004	8.544	6.922	1.731
tires and accessories	.120	.163	1.199	.986	.246
repairs	.151	.177	1.748	1.437	.360
other inter-city	.019	.027	.227	.187	.046
Equipment	2.65	3.209	27.309	22.465	4.493
Supplies	1.61	1.882	12.191	6.096	
Automobile Depreciation	---	-----	28.862	20.756	.415
Total	$6.30	$8.067	$97.561	$77.153	$18.821

* Millions of dollars.

multiplier of .75, which implies additional local income of $282,000 attributable to the proposed regulation (1, p. 242). This figure would grow to 415,000 by 1990 and to $463,000 by 2000 by allowing for increased lake visits in the future.

Table 2 contains estimates of increases in local income on a lake-by-lake basis for the years 1990 and 2000.

TABLE 2.--Estimate of Increases in Local Income (Thousands of $)

	Year	
Community Near Lake	1990	2000
Carlyle	$ 77.230	$ 84.863
Crab Orchard	24.624	27.456
Decatur	102.973	114.815
Rend	31.340	34.944
Shelbyville	76.110	86.111
Springfield	102.973	114.815
Total	$415.250	$463.004

Estimates of State Impact

From Table 1 we have expenditures of $77.153 million associated with usage of six Illinois lakes by urban visitors. We used the State Input-Output model to estimate the state-wide impact of this level of expenditures.[1]

The direct and indirect production (i.e., sales) of Illinois business stimulated by the expenditure of $77.153 is $49.771 million; and, when doubled to account for non-urban visitors, is about $100 million.[2]

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[1] Input-output results in the text are derived from computer runs furnished by Roger Christ, Illinois Bureau of the Budget (IBOB).

[2] This result is derived in the following manner. We supplied IBOB with expenditures of $144.7 million spent visiting 9 Illinois lakes by urban visitors. That expenditure implies $122.24 million in direct and indirect expenditures. This figure was adjusted upward by approximately $2.1 million by taking account of a more appropriate trade coefficient as

By 1990 urban and non-urban expenditures at six Illinois lakes would grow to $227.344 million and to $253,726 by the year 2000. The corresponding effect on Illinois production is $147 million and $164 million, respectively. The sectors with the largest production increases are exhibited in Table 3.

TABLE 3.--Statewide Impact of Recreational Expenditures (Millions of $)

	Year		
Sector	Present	1990	2000
Retail Trade	33.6	49.6	55.4
Wholesale Trade	12.4	18.2	20.4
Real Estate	4.2	6.2	7.0
Hotels and Lodging	3.6	5.4	6.0
Auto Repair	3.6	5.4	6.0
Motorcycles and Bicycles	3.2	4.8	5.4
Sporting and Athletic Goods	2.8	4.2	4.6
Petroleum Refining	2.4	3.6	4.0
Total	65.8	97.4	108.8

Finally, if the proposed phosphorus regulation increases lake visitation by 1% in 1990 and 2000, production in Illinois would increase by $1.47 million = (1%) ($147 million) and $1.64 million = (1%) (164 million)

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suggested by IBOB. Another increase of approximately $1.3 resulted from an error in the dollar amount of automobile depreciation used in deriving the input-output results. The figure used was $2.4 million rather than $52.4 for automobile depreciation, but the effect of the error was small (i.e., $1.3 million) because of the low level of automobile production in Illinois. In summary, expenditures on lake recreation of $194.7 million are associated with direct and indirect Illinois production of approximately $125.6. Therefore, $77.153 million in expenditures at six Illinois lakes implies $49.771 million = ($77.153/194.7)($125.6) million since the distribution of expenditures at the six lakes is the same at the nine lakes. Doubling this figure to account for non-urban visitors, yields an estimate of approximately $100 million.

respectively. The largest sector impacts would be 1% of those presented in Table 3.

The number of jobs associated with urban and non-urban expenditures at six lakes at present in 1990 and 2000 is 4,830, 7,120, and 7,950 respectively. Table 4 is a lake-by-lake distribution.

TABLE 4.--Jobs Associated with Recreational Expenditures

	Year		
Lake	Present	1990	2000
Carlyle	821	1,325	1,463
Crab Orchard	290	422	469
Decatur	1,280	1,760	1,972
Rend	333	542	595
Shelbyville	792	1,304	1,471
Springfield	1,314	1,767	1,980
Total	4,830	7,120	7,950

A 1% increase in visitation rates due to the proposed phosphorus regulation would increase the number of jobs by 71 and 80 in 1990 and 2000 respectively.

REFERENCES

1. Economics of Outdoor Recreation, Clawson, M. and Knetch, J. L., published for Resources for the Future, Inc., by The Johns Hopkins Press, 1966.

2. 1970 National Survey of Fishing and Hunting, U.S. Department of the Interior, Fish and Wild Life Service, Resource Publication #95.

3. Survey of Current Business, U.S. Department of Commerce, Table 7, July 12, 1976.

CHAPTER 6

OTHER PROPOSALS IN R76-1

In addition to the change in the phosphorus standard, R76-1 also proposes: (1) a change in Rule 404(a) relating to the effluent standard for suspended solids; (2) a change in the mechanism for reclassifying streams; and (3) changes to certain STORET numbers. The economic impact of each of these changes is discussed below.

Rule 404 (a)--Suspended Solids

The existing effluent standard prescribes that no effluent shall exceed 30 mg/l of five-day bio-chemical oxygen demand (BOD_5) and 37 mg/l suspended solids (except that higher limits are set for discharges to the Mississippi, Ohio and Wabash rivers). Since adoption of this standard, the federal law has been amended to require secondary treatment by municipal wastewater treatment plants. (By definition, secondary treatment requires an effluent BOD_5 of 30 mg/l and 30 mg/l for suspended solids.) The change in the suspended solids standard from 37 mg/l to 30 mg/l is the basis for the analysis that follows.

There are 101 dischargers in Illinois whose NPDES permits prescribe a "30/30" standard (BOD_5/suspended solids). There are 60 dischargers whose permits prescribe the "30/37" standard. The reason for this difference is that the 30/37 permits were presumably issued prior to publication of the federal "30/30" definition for secondary treatment. It is assumed that the 60 dischargers with "30/37" permits could have some economic impact from the proposed regulatory change.

In practice, most of the "30/30" and "30/37" dischargers are small waste treatment systems serving a population equivalent of 2,500 persons or less. Such waste systems in Illinois usually employ lagoons. Because of algal growths in lagoons, the discharge of suspended solids tends to be high--especially in summer. For this reason, the Illinois EPA requires some type of filter at the outfall. A simple third-stage cell with a sand bottom and an underdrain is the most widely used system. Experience has shown that such a system can easily meet the 30 mg/l suspended solids requirement. This means that no different or additional facilities will have to be built by the "30/37" permit holders, hence there will be no economic impact on the 60 "30/37" dischargers.

As a further consideration, a change to the federal regulation (40 CFR 133, October 6, 1977) exempts lagoons with less than 2 MGD design flow (20,000 population equivalent) from the suspended solids requirement, so long as it meets the design performance 90% of the time, and so long as it does not exceed the 30 mg/l BOD_5. As usual, stricter state standards will prevail. It thus appears that Illinois has the choice of: (1) retaining the "30/37" standard; (2) adopting the proposed "30/30" standard; or (3) eliminating the suspended solids standard for lagoons, relying on the 30 mg/l BOD_5 limitation to insure that excessive discharges of deoxygenating algae do not occur. There is no expected economic impact in any case.

Other proposed changes to Rule 404 are intended to correct or clarify wording or intent. These changes have no economic impact.

Rule 302 Secondary Contact and Indigenous Aquatic Life Waters

Chapter 3 establishes three stream classifications based on use designations. "General Use" and "Public and Food Processing Water Supply" classifications are the same except for two specific river exemptions to the Public and Food Processing Water Supply classifications. The other classification, "Secondary Contact and Indigenous Aquatic Life Waters," names specific rivers, or reaches, which for various reasons cannot be expected to meet the higher standards of the other use classifications. Paragraph 302 (k) adds to the list: "All waters in which, by reason of low flow or other conditions, a diversified aquatic biota cannot be satisfactorily maintained even in the absence of contaminants." This provision suggests that any intermittent stream (no dry-weather flow), of which there are hundreds in the state, are automatically exempt from the higher general use/public and food processing standards.

The Pollution Control Board has made it clear that any additions to the list of secondary contact waters will be only as a result of specific Board action to amend Rule 302. The proposed amendment will delete the present wording of Paragraph 302 (k) and substitute words which specify the Board's intent to address all changes to Rule 302 on a case-by-case basis, and in accordance with published procedural rules.

There will be no economic impact from this proposed change.

Changes to Certain STORET Numbers

STORET is a system promulgated by the U.S. EPA for coding environmental data for computer processing and retrieval. STORET numbers are specified in Chapter 3 for the various parameters that define Illinois water quality and effluent standards. Implicit in the STORET number is not only the name and concentration of the constituent being measured, but also the laboratory process by which the monitoring sample is analyzed.

STORET numbers are included in the regulations along with the constituent name and allowable concentration.

The changes to the STORET numbers proposed in this regulation will correct previous errors, or will specify different or preferred analytical methods. There is no significant economic impact to this proposed change.

APPENDIX 1

STATE OF ILLINOIS)
) SS
COUNTY OF SANGAMON)

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

PETITION FOR REGULATORY CHANGE)
TO THE WATER POLLUTION REGULATIONS) PCB R 76-1
OF THE ILLINOIS POLLUTION CONTROL)
BOARD)

PETITION FOR REGULATORY CHANGE

The Illinois Environmental Protection Agency, (hereinafter "Agency") pursuant to Sections 1004(j) and 1028 of the Illinois Environmental Protection Act (Ill. Rev. Stat., Chapter 111 1/2, Sections 1001 et seq. 1973) hereby requests the Illinois Pollution Control Board (hereinafter "Board") to make the following changes to its Water Pollution Regulations (Chapter Three):

I. Phosphorus

Rule 203(c) - Delete

Rule 407(c) - Add new Rule to read:

(c) No effluent from any source which discharges to a lake or reservoir with a surface area of 20 acres or more or to any tributary to such a lake or reservoir and whose untreated waste load is 1500 or more population equivalents shall contain more than 1.0 mg/l of phosphorus as P.

Rule 407(d) - Add new Rule to read:

(d) For the purpose of this Rule 407 the term "lake or reservoir" shall not include low-level pools constructed in free flowing streams.

Rule 407(e) - Add new Rule to read:

(e) Compliance with the limitations of this Rule 407(c) shall be achieved by the following dates:

(i) new sources shall comply on the effective date of this regulation, and

(ii) existing sources shall comply by December 31, 1978.

(new language underlined)

JUSTIFICATION

Water quality data collected by the Agency has indicated that large percentage of monitoring stations show high levels of phosphorus. These levels do not generally represent a threat to free flowing streams but may seriously increase eutrophication rates of lakes and reservoirs to which these streams may be tributary.

Eutrophication studies of Illinois lakes undertaken by the USEPA and studies of the upper Sangamon River tributary to Lake Decatur done by the Illinois State Water Survey (ISWS) show that sources of phosphorus fall into two major categories: point sources and non-point sources.

The point sources of phosphorus are from wastewater discharges such as municipal sewage treatment plants and industrial facilities while non-point sources are primarily run-off waters from farm lands fertilized with phospate base fertilizers.

Both USEPA and ISWS reports show that the contribution of point source dischargers to the total phosphorus problem of tributaries to lakes and reservoirs is small compared to the non-point source contribution.

Since Chapter 3 is designed primarily for point source control, the proposed regulatory change is aimed at requiring significant phosphorus contributors to provide their fair share of control of this pollutant. The change requires that significant (1500 P. E.) point source contributors of phosphorus to lakes and reservoirs must treat their wastewater prior to discharge to a level not to exceed 1 mg/l. This level represents the generally accepted treatability limit for this pollutant.

The Agency recognizes that the phosphorus problem will not be completely solved until the non-point sources are controlled. This area is being addressed through the planning activities being carried out by the Agency and others and if necessary, regulations will be proposed in this area to assure that phosphorus is not the cause of eutrophication of Illinois lakes.

Rule 407(e) provide for a compliance program for point source discharges. This compliance program provides for immediate ompliance by new sources and compliance by December 31, 1978 for xisting sources. The December 31, 1978 date contemplates developent of a non-point source control strategy for phosphorus by mid-978. This is consistent with Section 208 of the Federal Water ollution Control Act Amendments of 1972, which contains planning equirements for point and non-point sources pollution in designated nd non-designated areas in the State of Illinois.

II. Rule 404

Rule 404(a) - Modify to read:

(a) On and after July 1, 1972, or such earlier date as may have been specified in Rules and Regulations SWB - 7 through SWB - 15, no effluent shall exceed 30 mg/l of five-day biochemical oxygen demand (BOD5) (STORET number 00310) or ~~37~~ 30 mg/l of suspended solids (STORET number 00530), except as follows:

Rule 404(c)(iii)(D) - Modify to read:

(D) The deoxygenating constituents of the effluent ~~does~~ do not, alone or in combination with other sources, cause a violation of the applicable dissolved oxygen water quality standard. ~~standards~~.

Rule 404(f)(ii) - Modify to read:

(A) The deoxygenating constituents of the effluent shall not, alone or in combination with other sources, cause a violation of ~~any~~ the applicable dissolved oxygen water quality standard; and

Delete B

(B)(~~C~~) The effluent shall not exceed 10 mg/l of BOD5 or 12 mg/l suspended solids; and

(C)(~~D~~) The owner or operator of such source shall file with the Agency the Project Completion Schedule required by Rule 1002 of this Chapter. In addition to the requirements of Rule 1002, such schedule shall include a program for achieving compliance with the above conditions and with applicable water quality standards, including, but limited to, dissolved oxygen, bottom deposits, ammonia nitrogen, and phosphorus, with particular reference to nitrogenous oxygen demand and to the control of storm-water overflows; and

(D)(~~E~~) The Agency finds that the program will within the compliance dates otherwise applicable assure compliance with the conditions of this subparagraph.

Rule 404(h) - Modify to read:

(h) Compliance with the numerical standards in this Rule 404 shall be determined on the basis of the type and frequency of sampling prescribed by the NPDES permit for the discharge at the time of monitoring.

(new language underlined)

JUSTIFICATION

Rule 404 deals with effluent limits for deoxygenating wastes. These constituents represent the primary elements of concern in domestic waste and are, therefore, of great importance to municipal sewage plants.

The changes to Rule 404(a) and 404(h) are simply to make Illinois Regulations consistent with Federal requirements and procedures. Rule 404(h) has been modified to reference the sampling procedure set forth in the discharger's NPDES permit. These changes are presently reflected in NPDES permits being certified by the Agency.

Changes to Rule 404(c)(iii)(D) and Rule 404(f)(ii)(A) are intended to clarify the intent of the existing regulations. Rule 404(f)(ii)(B) was deleted to avoid repetition with new Rule 404(f)(ii)(A). Rule 404(c)(iii) and 404(f)(ii) describes exemptions from very stringent limits on deoxygenating wastes for certain dischargers. To qualify for this exemption, these dischargers must demonstrate, among other things, that discharge of deoxygenating wastes at levels higher that those otherwise required will not cause violation of the dissolved oxygen water quality standard in the receiving stream. The revision to these rules would limit the scope of such a demonstration to those constituents directly affecting the dissolved oxygen level of the receiving stream.

III. Rule 302

Rule 302 - Modify to read:

Secondary Contact and Indigenous Aquatic Life Waters

Secondary Contact and Indigenous Aquatic Life Waters are those waters not suited for general use activities but which will be appropriate for all secondary contact uses and which will be capable of supporting an indigenous aquatic life limited only by the physical configuration of the body of water, characteristics and origin of the water and the presence of contaminants in amounts that do not exceed the Rule 205 water quality standards. The following are designated as Secondary Contact and Indigenous Aquatic Life Waters:

(a) The Chicago Sanitary and Ship Canal;

(b) The Calumet - Sag Channel;

(c) The Little Calumet River from its junction with the Grand Calumet River to the Calumet - Sag Channel;

(d) The Grand Calumet River;

(e) The Calumet River

(f) Lake Calumet;

(g) The South Branch of the Chicago River;

(h) The North Branch of the Chicago River from its confluence with the North Shore Channel to its confluence with the South Branch;

(i) The Des Plaines River from its confluence with the Chicago Sanitary and Ship Canal to the interstate 55 bridge; and

(j) The North Shore Channel, except that dissolved oxygen in said Channel shall be not less than 5 mg/l during 16 hours of any 24 hours period, nor less than 4 mg/l at any time.

(~~k~~) Delete k

Additions or deletions to the above list are governed by Part II of the Illinois Pollution Control Board's Procedural Rules.

(new language underlined)

JUSTIFICATION

Much confusion has been generated in efforts by various people to interpret Rule 302, especially subpart (k). The regulatory change presented here is an attempt by the Agency to clarify the intent of this Rule and more clearly set forth the mechanism for reclassification of streams other than those specifically named.

IV. Changes to Certain Storet Numbers

RULE	CONSTITUENT	PRESENT STORET #	PROPOSED STORET #
203(f)	Arsenic (Total)	01000	01002
	Barium (Total)	01005	01007
	Boron (Total)	01020	01022
	Cadmium (Total)	01025	01027
	Copper (Total)	01040	01042
	Fluoride	00950	00951
	Lead (Total)	01049	01051
	Nickel (Total)	01065	01067
	Selenium (Total)	01145	01147
	Silver (Total)	01075	01077
	Total Dissolved Solids	00515	70300
	Zinc	01090	01092
204(b)	Arsenic (Total)	01000	01002
	Barium (Total)	01005	01007
	Cadmium (Total)	01025	01027
	Oil - Hexane Solubles or Equivalent	00550	00550, 00556, or 00560
	Selenium (Total)	01145	01147
	Total Dissolved Solids	00515	70300
	Lead (Total)	01049	01051
206(c)	Total Dissolved Solids	00505	70300
404(a)	Suspended Solids	-----	00530
408(a)	Oil - Hexane Solubles or Equivalent	00550	00550, 00556, or 00560
	Selenium (Total)	01145	01147
408(b)	Total Dissolved Soids	00515	70300

(new Storet numbers underlined)

JUSTIFICATION

Errors now appear in some of the storet numbers and create confusion in identification and measurement procedures.

WHEREFORE, the Illinois Environmental Protection Agency requests that the Illinois Pollution Control Board, pursuant to Section 1028 of the Illinois Environmental Protection Act, hold public hearings to enable the Agency to present its proposal and to enable the Board to evaluate the proposed rule changes and hear relevant evidence on the suggested modifications.

Submitted by

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Date: January 5, 1976

APPENDIX 2

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page 1 of 3

ASSESSMENT WORKSHEET
CROSS-CHECKLIST FOR BENEFIT CONSIDERATIONS
economic impact study

ALTERNATIVE ASSESSED ____________

DESCRIPTION ____________

REGULATION NO. R76-1 IIEQ PROJECT NO. 80.063 TITLE: An Economic Impact Analysis Phosphorous Control

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	
Health								
Digestive System	Gastrointestinal distress from ingestion of water where certain blue-green algae have bloomed - even when algae no longer present	P 137						All potential benefits to be derived from control of algae growth
Skin Irritation	"Swimmers' itch" from organism harbored by snails which breed in floating mats of vegetation.	P 138						Page reference, 137-138, from testimony of Kenneth M. Mackenthun at hearing on R76-1, 9/9/76.
Biotic								
Microflora Aquatic Plants	Reduction of these are the prime benefit of phosphorus control	P 137						
Fauna	Occasional death to mammals and fish from ingestion.	P 137						
Fish and shellfish	Occasional fish kills assoicated with high levels of euthrophication.	P 137						
	Stunted or undesirable fish populations associated with dense plant populations.	P 138						
Insects	Biting flies find breeding ground in floating mats of vegetation	P 138						
Aesthetic and Human Interest								
Scenic Views and Vistas								
Open Space Qualities	Control of unsightly and foulsmelling water conditions.	P 137						

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	
Recreational								
Fishing Boating Swimming	Activities impeded by floating algal mats or rooted plants at surface. Reduced visibility, possibility of entanglement	137						Primary benefits. Estimates pertain to total value added to lakes by R76-1; individual categories not distinguished, as in unit day value approach.
Camping and Hiking Picknicking Resorts	Some secondary impact expected							Primary benefits are the appropriate figures for use in cost-benefit comparisons.
		Table 17 Ch. 4		1990-2000 Pres.val at 8%		$1,052,000	Large	Benefits calculated for six lakes, which pertain to about 86% of lakes and dischargers affected by R76-1.
				2000+ in perpetuity Pres.val at 8%		4,537,000		
	Pres. val. (1979) of benefits required to cover costs					5,589,000		1% of lake consumer surplus, between 1990-2000, plus 5.3% of lake consumer surplus, after 2000. Estimates of primary benefits are high in that they represent minimum benefits necessary to make R76-1 cost effective.
Industrial/ Commercial			Small for non-point	R76-1 in control.	absence of			
Equipment	Filter clogging problems at municipal water installations occasionally result from abundant suspended algae.	137						
Land Values Residential Land Values	Increases expected in response to water quality improvement.							
Government								
Research	Knowledge gained from monitoring results of phosphorus control at individual lakes a major potential benefit.							
Information								
Costs of R76-1; Reasonable Lower-Bound Estimate		Ch. 4		Value accumulated in perpetuity at 8%		$6,764,000		—

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty 1990	$ Value 2000	Range of $ Uncertainty	
Lake-byLake Breakdown of Secondary Impact: Income Local	Carlyle	Table 2 Ch 5			$ 77,230	$ 84,863	Large	Impact on income will reflect real or price changes depending on economic conditions prevailing at the time.
	Crab Orchard				24,624	27,456		
	Decatur				102,973	114,815.		
	Rend				31,340	34,944		
	Shelbeyville				76,110	86,111		
	Springfield				102,973	114,815		
Secondary Impact: Income Generated Locally by R76-1 Total for Six Lakes					$415,250	$463,004		Secondary benefits represent impact on general economic conditions, as opposed to benefits of regulation appropriate for comparison with costs. Values are not discounted.
Lake-by-lake Breakdown of Secondary Impact: Income State-wide	Carlyle				273,000	302,000	Large	See coments for impact on local income.
	Crab Orchard				87,000	97,000		
	Decatur				363,000	407,000		
	Rend				112,000	123,000		
	Shelbyville				269,000	303,000		
	Springfield				365,000	408,000		
Total					1,470,000	1,640,000		
Lake-byLake Breakdown of Secondary Impact: Employment State-wide	Carlyle				13	14	Large	Impact on employment will represent additional employment or employment diverted from competing uses, depending on economic conditions prevailing at the time. Number of jobs may be overestimated because of inflationary effects on the value of man-years of employment per unit of output.
	Crab Orchard				4	5		
	Decatur				18	20		
	Rend				5	6		
	Shelbyville				13	15		
	Springfield				18	20		
Total					71	80		
Taxes Income Taxes					$29,650	$33,000	Large	Assume each job created has four income tax exemptions associated with it. For example, the 80 jobs created in year 2000 will have 320 person exemptions associated with them. Income sjubect to tax is $1,320,000=$1,690,000-(320) ($1000 per exemption). Total tax is $33,000=$1,320,000 (.025 tax rate).
Sales Taxes					$47,775	$53,300		Assume that 65% of gross income is spent on goods subject to 5% sales tax.

APPENDIX 3

Sample Cost Calculation

A sample cost calculation for an alum addition for a hypothetical community of 10,000 people follows. The methodology of this sample calculation is similar to that followed in the COST program.

1. 90% reduction of phosphorus requires a mole ratio of aluminum to phosphorus of 2.1:1. This implies a weight ratio of (2.1)(26.98):(1)(30.97) or a weight ratio of 1.829:1.

2. Alum has a minimum aluminum content of 17%, expressed as Al_2O_3, which corresponds to a 9.1% concentration of aluminum. Thus, the weight ratio of alum to phosphorus is 1.829/(.091):1 or 20.10:1.

3. Assuming 10 mg/l of P, an alum dosage of 20.10(10) = 201 mg/l would be required for 90% phosphorus removal. The dosage corresponds to 1674 lbs/million gal of 1.674 lbs/1000 gals.

4. Let us assume that the community in question is approximately 110 miles from Joliet and approximately 165 miles from East St. Louis. Shipping rates for liquid alum are $.705 from Joliet and $1.000 from East St. Louis; rates are on a 100 lb weight basis. Liquid alum rates are based on a 40,000 lb. minimum shipment, and liquid alum weighs approximately 11.1 lbs per gallon and one gallon contains 5.4 lbs of dry alum. Therefore, a 40,000 lb shipment contains about 3,600 gallons of liquid alum. The purchase of one pound of alum would require paying for 2.055 lbs = (11.1 lbs/gal)/(5.4 lbs alum/gal) of material as far as shipping charges are concerned. In order to treat 1,000 gallons of influent, liquid alum shipment costs would be:

From Joliet: (1.674 lb/1000 gal)($.00705/lb)(2.055 lb) =
$.0243/1000 gal

From East St. Louis: (1.674 lb/1000 gal)($.01/lb)(2.055 lb) =
$.0344/100 gal

We conclude that liquid alum would be purchased from the Joliet supplier since costs shipment are lower.

5. Liquid alum costs $79 per ton or $.0395/lb. A sewerage treatment plant serving a community of 10,000 people would have a flow of 1,000,000 = (10,000 people x 100 gal/person) gallons per day. Total alum

costs per year are:

Liquid alum: [(1.674 lb/1000 gal) x ($.0395/lb) + $.0243/1000 gal] x (1000) x (365 days) = $33,004/yr.

6. The polymer dosage is assumed to be a .5 mg/l (2, pp. 4-21). The equivalent dosage in pounds per 1000 gallons is .0042 lb/1000 gal. Total polymer costs are

(.0042 lb/1000 gals) x ($1.97) x (1000) (365 days) = $3020/yr.

7. Total yearly chemical costs are:

Liquid alum plus polymer: $33,004 + $3,020 = $36,024

8. The handling of additional sludge is expected to increase variable costs of sewerage treatment plants by $.035 per 1000 gallons for a 1 MGD plant (3, p. III, 48, 49, 57, 58).

Costs for dewatering and incineration of sludge from a conventional activated sludge process were subtracted from sludge costs for a plant with an alum addition in the primary treatment process. The estimate of $.035/1000 gal for variable sludge costs was calculated for February, 1973, when the value of the Wholesale Price Index for Industrial Commodities was at the 120.0 level. As recommended, costs were updated to July, 1977 by using the relationship (3, p. B-3).

$$(\$.035/1000\text{ gal})\ \frac{(194.8)}{120} = \$.0568/1000\text{ gal}$$

where the estimated value of the Wholesale Price Index for Industrial Commodities for July, 1977 is 194.8.

Variable sludge costs attributable to an alum addition for a 1 MGD plant are

($.0568/1000 gal) (1000) (365 days) = $20,732

9. An alum addition would require some additional capital expenditures for feeding equipment, storage tanks, pumps and possibly for the handling of additional sludge. Capital cost for a 1 MGD plant for liquid alum feed facilities is $15,000 in 1973 prices @2, pp. 10-17). Updating by the USEPA's 5 MGD plant cost index yields a current cost estimate of $15,000 (1.22) = $18,300. Capital costs due to additional sludge are estimated at $.005/1000 gal (3, p. III 48, 49, 57, 58). The latter figure is an amortization calculation at 5-5/8%. The corresponding yearly figure is

($.005/1000 gal) x (1000) (365 days) = $1,825/yr

which in turn implies an original capital investment of

($1,825) (11.83) = $21,590

where 11.83 is the present value of an annuity of $1 for 20 years at 5-5/8%. We estimate additional capital costs due to an alum addition as $18,300 + $21.590 = $39,890. The yearly amortization of this figure at 10% for 20 years is

$$\frac{\$39,895}{8.51} = \$4,687/yr$$

where 8.51 is the present value of an annuity of $1 for 20 years at 10%.

10. Yearly costs for a liquid alum addition for a 1 MGD plant would be:

Costs	
Chemicals	$36,024
Sludge	20,732
Capital	4,687
	$61,443

Approximately 2/3 of the foregoing totals is attributable to chemical costs and capital equipment related to chemical usage. Additional variable and fixed sludge costs account for the remaining one-third of the totals. This may be significant because some evidence indicates very small additional costs due to sludge (7). Cost estimates based on smaller incremental sludge costs are presented later.

The foregoing estimate of chemical costs is calculated from assumptions involving the mole ratio of aluminum to phosphorus that is required to reduce phosphorus concentration by 90%. The estimated cost is:

(1.674 lb/1000 gal) x ($.0395/lb) + $.0234/1000 gal = $.0904/1000 gal

A USEPA publication, A Guide to the Selection of Wastewater Treatment Systems can be used to get an independent chemical cost of an alum addition (3). Unit process A-4 of that report is a primary sedimentation with an alum addition operation. Process A-1 is primary sedimentation. The difference in operating costs between A-4 and A-1 gives a rough estimate of the chemical costs of an alum addition; about $.05/1000 gal for a 1 MGD plant (3, p. III 14, 17). This estimate is based on an alum dosage of

170 mg/l or 1.420 lb/1000 gals. The implicit mole ratio between aluminum and phosphorus is about 1.6:1, which is necessary to achieve 80% phosphorus reduction in an influent with 11 mg/l of phosphorus. With 80% phosphorus reduction, approximately 2.2 mg/l of phosphorus will remain in the effluent. However, our estimates are based on a mole ratio of aluminum to phosphorus of 2.1:1--a 17.9% larger dose of alum. Increasing the cost estimate from that source by 17.9% yields an estimate of $.05 (1 + 17.9%) = $.0590. Adjusting the later figure for price increases gives us an estimate of $.0590 (1.62) = $.0956. This estimate is quite close to the estimate of $.0904/1000 gal.

All the cost estimates for an alum addition or ferric chloride addition follow the procedure outlined above for the hypothetical 1 MGD sewerage treatment plant. However, plants with a flow larger than 1 MGD have capital costs larger than $15,000 (in 1973 prices). Costs for tanks, feed equipment, and pumps total $50,000 (in 1973 prices) for a 10 MGD plant (2, pp. 10-17). Capital costs for plants with flows between 1 and 10 MGD were assumed to increase linearly between 1 and 10 MGD. WWTP with flows of less than 1 MGD are assumed to have capital costs that are an average of two rather extreme assumptions. One assumption is that there is no reduction in capital costs for smaller plants and another assumption might be that capital costs decrease proportionally with flow. We used an average of the capital costs implied by these assumptions. This procedure is partially justified on at least two grounds. First, capital costs are rather small when amortized to a yearly dollar value and any error would be rather small in its effect on the total cost of an alum or ferric chloride addition. Secondly, the $15,000 (in 1973 prices) provides for the storage of 6,000 gallons of liquid alum. It is desirable for smaller plants to have approximately the same amount of storage capacity in order to take advantage of bulk shipping rates. In order to take advantage of such rates, orders must be for approximately 4,000 gallons of material. A plant, for example, with a daily flow of 200,000 gallons would use:

$$(1.674 \text{ lbs/1000 gal})\ (200)\ (365) = 122{,}202 \text{ lbs}$$

of alum per year. The number of gallons of liquid material actually shipped throughout one year is

(122,202 lbs of alum)/(5.4 lbs alum/gal) = 22,630 gal.
This would require about five or six 4,000 gallon shipments per year, and allow some flexibility in ordering and receiving shipments (2, pp. 10-17).

A final comment should be made regarding one of the sources of our information (3). As far as we can determine, costs were estimated for various wastewater treatment processes for plants with flows of 1, 5, 20 and 100 MGD (3, p. 4). Costs curves are graphed on a "¢/1000 gal" basis for flows between 1 and 100 MGD and regression equations are listed in Appendix B of that source. We used the information in that source to estimate dewatering costs of sludge, incineration costs and possible capital costs associated with additional sludge at a flow rate of 1 MGD. This was done by actually reading cost estimates off the graphs rather than using the regression equations.

APPENDIX 4

MATHEMATICS OF DISCRIMINANT ANALYSIS

The Discriminant Function

Let us denote two groups as Group 0 and Group 1. Assume we have a sample of size n_o of known members of Group 0 and a similar sample of known members of Group 1 which is of size n_1. The total sample is $n = n_0 + n_1$, and each item in the sample is referred to as a case or observation. If there are p predictor variables of interest, we can denote the ith observation in the sample as

$$X_{i1}, X_{i2}, \ldots\ldots, X_{ip}$$

where X_{i1} is the value of the first predictor variable for the ith case, X_{i2} is the value of the second predictor variable for the ith case, and, in general, X_{ij} would be the value of the jth predictor variable for case i. The index i ranges from 1 to n and j ranges from 1 to p. The discriminant coefficient for the jth predictor variable is denoted by b_j and we let Z_i be the discriminant score for the ith case. Finally, Z_c is a critical discriminant score used in classifying cases into Group 0 or Group 1.

The discriminant function is a linear combination of predictor variables which has the form

$$Z_i = b_0 + b_1X_{i1} + b_2X_{i2} + \ldots + b_pX_{ip}$$

The classification rule of discriminant analysis is:

Classify a case into Group 0 of $Z_i > Z_c$

Classify a case into Group 1 if $Z_i < Z_c$

where Z_c is chosen in such a way as to minimize the probability of misclassification.

The discriminant function itself is estimated from the sample of known members of Group 0 and Group 1. Estimating the discriminant function amounts to determining the values of the discriminant coefficients $b_0, b_1, \ldots\ldots, b_p$. Once estimated, the discriminant coefficient b_j tells us the impact a chance of one unit in X_{ij} has on the discriminant score Z_i, i.e., b_j is interpreted as a marginal impact.

Effectiveness of Classification

The classification table for the entire sample (used to calculate the discriminant function) can be used to get a very rough measure of the adequacy of the discriminant function. This table has the form:

CLASSIFICATION TABLE
PREDICTED GROUP MEMBERSHIP

		Group 0	Group 1	Table
Actual Group Membership	Group 0	n_{00}	n_{01}	n_0
	Group 1	n_{10}	n_{11}	n_1
	Totals	n_0*	n_1*	n

n_{00} = Group 0 members actually classified into Group 0 by using the discriminant function

n_{01} = Group 0 members classified into Group 1

n_{11} = Group 1 members classified into Group 1

n_0* = Total number of cases classified into Group 0

n_1* = Total number of cases classified into Group 1

The number of correct classifications is $(n_{00} + n_{11})$, and incorrect classifications are $(n_{01} + n_{10})$ in number. The percentage of correct classifications is $(n_{00} + n_{11})/n$.

The entire set of n observations is used to estimate the discriminant function and then these same observations are classified (into one of two groups) by using the function. The percentage of correct classifications is positively biased when such a classification table is constructed (2). To deal with this problem we estimate a discriminant function with only a portion of the sample data available and use this function to classify cases from the remainder of the sample data. This procedure enables us to get a more accurate measure of the adequacy or "discriminating power" of the estimated function.

We must know the probability (i.e., percentage) of correct classifications due to pure chance in order to evaluate the adequacy of a discriminant function. The idea is that classification with a discriminant function should be considerably more accurate than what could be expected by a pure chance classification. There are three types of pure chance models that could be used as a yardstick to measure the adequacy of a discriminant function (4).

Maximum Chance Model

Assume that α is the a priori probability of a case belonging to Group 0. The a priori probability of an observation being drawn from Group 1 is $(1 - \alpha)$. Let C_M denote the larger of α and $1 - \alpha$. Then the percentage correctly classified would be C_M by simply classifying every case into the group with the larger a priori probability.

For example, let the a priori probabilities of Group 0 and Group 1 membership be .25 and .75, respectively. By classifying every case into Group 1 we would achieve 75% correct classification but 25% of the classification would be incorrect.

Proportional Chance Model

Once again, α and $(1 - \alpha)$ denote the a priori probabilities of membership in Group 0 and Group 1, respectively. Now, let p and $(1 - p)$ denote the actual percentage (or proportion) classified into Group 0 and Group 1, respectively. The probability of correct classifications due to pure chance would be

$$p\,\alpha + (1 - p)(1 - \alpha)$$

That is, the probability of correct classification into Group 0 is equal to the percentage actually classified into Group 0 (i.e., p) weighted by the probability of observing a member of Group 0 (i.e., α). Similarly, the probability of correctly classifying into Group 1 is equal to the percentage actually classified in that group (i.e., $[1 - p]$) weighted by the probability of Group 1 membership (i.e., $[1 - \alpha]$).

In the proportional chance model we wish to classify the same percentage of cases into each group as the a priori probability of membership in each group. This means that $p = \alpha$, and the probability of correct classifications due to chance is

$$C_p = \alpha^2 + (1 - \alpha)^2$$

If $\alpha = .25$ as above,

$$C_p = (.25)^2 + (1 - .25)^2$$
$$= .65$$

A random classification (constrained only by the condition that 25% and 75% of the cases are classified into Group 0 and Group 1, respectively) would result in 62.5% correct classification and 37.5% incorrect classification.

Variable Chance Model

This model is a generalization of the Proportional Chance Model. In this model p and α are not necessarily equal. The probability of correct classification due to chance would be

$$P_v = p\alpha + (1 - p)(1 - \alpha)$$

As an example, let $p = .20$ and $\alpha = .25$, i.e., 20% are actually percentage classified in Group 0, while the *a priori* probability of Group 0 membership is 25%. In this case

$$P_v = (.2)(.25) + (1 - .20)(1 - .25)$$
$$= .65$$

A random classification would result in 65% of the cases being correctly classified.

If Group 0 and Group 1 are of equal size (i.e., $\alpha = .5$) all three models yield the result that random classification would be correct 50% of the time.

For the Maximum Chance Model: $C_M = \text{larger of } \alpha \text{ and } (1 - \alpha) = 50\%$

For the Proportional Chance Model: $C_p = {}^2 + (1 - \ )^2 = 50\%$

For the Variable Chance Model:

$$\begin{aligned} C_v &= p\alpha + (1 - p)(1 - \alpha) \\ &= p(.5) + (1 - p)(.5) \\ &= .5[p + (1 - p)] \\ &= 50\% \end{aligned}$$

Consider the following hypothetical classification table:

HYPOTHETICAL CLASSIFICATION TABLE
PREDICTED GROUP MEMBER

		Group 0	Group 1	Totals
Actual Group Membership	Group 0	60	40	100
	Group 1	60	840	900
	Totals	120	880	100

Ninety percent of the cases are classified correctly in the table. How good is this relative to the three chance models? The chance probability levels for the three models are:

Maximum Chance Model: $C_M = .90$

Proportional Chance Model: $C_P = (.1)^2 + (.9)^2 = .81$

Variable Chance Model: $C_v = (.12)(.10) + (.88)(.90) = .804$

The classification table does no better than the Maximum Chance Model. Assigning all cases to Group 1 yields the same percentage of correct classifications as the classification table. If our sole purpose is to maximize overall correct classification, there would be little reason to calculate a discriminant function or construct a classification table since that exercise does not improve over the Maximum Chance Model. However, we usually are interested in classifying some cases into each group. When cases are classified into Group 0 we are, so to speak, defying the odds since the *a priori* probability of Group 0 membership is only 10%. The Proportional and Variable Chance Models take this low probability into account--the two models yield probabilities of 81% and 80.4%, respectively for correct classification due to pure chance. The hypothetical classification table is much more adequate relative to these probability levels. In addition, notice that 50% of the cases assigned to Group 0 are correctly classified in the hypothetical table. This percentage is quite high since the *a priori* probability of Group 0 membership is only 10%. The *a priori* probability of Group 1 membership is 90%, but the hypothetical table is correct 95.45% (=840/880) of the time when a case is assigned to Group 1.

In the following classification table both groups are the same size. This implies a 50% success rate for all three chance models.

HYPOTHETICAL CLASSIFICATION TABLE
PREDICTED GROUP MEMBERSHIP

		Group 0	Group 1	Totals
Actual Group Membership	Group 0	80	20	100
	Group 1	40	60	100
	Totals	120	80	200

Seventy percent of the group assignments are correct in the classification table, 66% of the Group 0 assignments are correct and 75% of the assignments are correct for Group 1. These results represent a considerable improvement over the pure chance models.

In the present study the probabilities for the various chance models are:

Maximum Chance Model: $C_M = \text{larger of } [.179, .821]$
$= 82.1\%$

Proportional Chance Model: $C_p = \alpha^2 + (1 - \alpha)^2$
$= (.179)^2 + (.821)^2$
$= 70.6\%$

Variable Chance Model: $C_v = p\alpha + (1 - p)(1 - \alpha)$
$= (.149)(.179) + (.851)(.821)$
$= 72.6\%$

As presented in Chapter 3, Table 1, the actual percentage of correct classifications is 90.8%. The latter value is considerably in excess of what could be due to chance.

Mathematics of the Discriminant Function

Lex x be a (pxl) vector of predictor variables. The multivariate probability density functions for Group 0 and Group 1 are denoted for $f_0(x)$ and $f_1(x)$, respectively. As above, let α and $(1 - \alpha)$ be the a priori probabilities of Group 0 and Group 1 membership. In discriminant analysis we seek two regions (say) R_0 and R_1 such that a case is classified in Group 0 if the $x \varepsilon R_0$ and in Group 1 if $x \varepsilon R_1$ (1, pp. 128-129). (The regions R_1 and R_2 are subspaces of a p-dimensional Euclidian space and must possess the properties of being disjoint and exhaust the entire Euclidian space, i.e., $R_0 \ R_1 = \phi$ and $R_0 \ R_1 = R^P$.) The following probabilities are of interest:

- probability of correct classifying a case into Group 0 given that the case actually belongs to Group 0

$$\underset{R_0}{f_0(x)dx}$$

- probability of incorrectly classifying a case into Group 1 given that the case actually belongs to Group 0

$$\underset{R_1}{f_0(x)dx}$$

- probability of correctly classifying a case into Group 1 given that the case actually belongs to Group 1

$$\underset{R_1}{f_1(x)dx}$$

- probability of incorrectly classifying a case into Group 0 given that the case actually belongs to Group 1

$$\underset{R_0}{f_1(x)dx}$$

- probability of drawing a case from Group 0 and correctly classifying it

$$\alpha \ \underset{R_0}{f_0(x)dx}$$

- probability of drawing a case from Group 0 and incorrectly classifying it

$$\alpha \ \underset{R_1}{f_0(x)dx}$$

- probability of drawing a case from Group 1 and correctly classifying it

$$(1 - \alpha) \quad \underset{R_1}{f_1(x)dx}$$

o probability of drawing a case from Group 1 and incorrectly classifying it

$$(1 - \alpha) \quad \underset{R_0}{\;} f_1(x)dx$$

The expected percentage of misclassifications is given by:[1]

$$M = \alpha \quad \underset{R_1}{\;} f_0(x)dx + (1 - \alpha) \quad \underset{R_0}{\;} f_1(x)dx$$

$$= \quad \underset{R_1}{\;} [\alpha\ f_0(x) - (1 - \alpha)f_1(x)]dx + (1 - \alpha)$$

The value of M is minimized by defining the region R_1 to be the set of all x that makes the integrand quantity $[\alpha\ f_0(x) - (1 - \alpha)f_1(x)]$ negative. This insures that the integral over R_1 is made as small as possible and thus M is minimized. Therefore, we can say that the percentage of misclassifications M is minimized if R_1 is defined as the set of all x such that

$$\alpha f_0(x) - (1 - \alpha)f_1(x) < 0$$

The region R_0 is defined by

$$\alpha f_0(x) - (1 - \alpha)f_1(x) > 0$$

The diagram on the next page illustrates these results assuming only one normally distributed predictor variable. In this illustration it is assumed that $\alpha < (1 - \alpha)$ since the dividing point between regions R_0 and R_1 lies to the left of the intersection of the $f_0(x)$ and $f_1(x)$ densities.

---

[1] If we know the costs of misclassification (say) C(0/1) and C(1/0), we could specify the expected cost of misclassification as

$$C(1/0)\alpha \quad \underset{R_1}{\;} f_0(x)dx + C(0/1)(1 - \alpha) \quad \underset{R_0}{\;} f_1(x)dx$$

where C(0/1) is the cost of classifying a case into Group 0 if it actually belongs to Group 1 and C(1/0) is the cost of classifying a case into Group 1 if it actually belongs to Group 0.

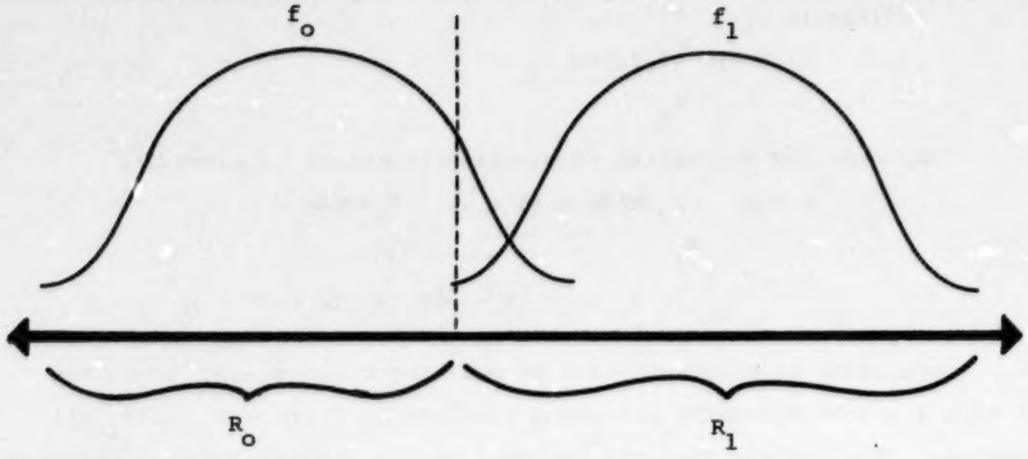

Fig. 1

$$R_o = x \quad \frac{f_o(x)}{f_1(x)} \quad \frac{(1-\alpha)}{\alpha} \quad \text{or } R_o = x \quad \alpha f_o(x) > (1-\alpha)f_1(x)$$

$$R_1 = x \quad \frac{f_o(x)}{f_1(x)} \quad \frac{(1-\alpha)}{\alpha} \quad \text{or } R_1 = x \quad \alpha f_o(x) < (1-\alpha)f_1(x)$$

Let μ_0 and μ_1 be (pxl) vectors of group means and Σ be the variance-covariance matrix for x which is assumed to be multivariate normal.[1] The multivariate normal probability density function for Group 0 would be: (3, pp. 342, 346)

$$f_0(x) = (2\pi)^{-\frac{p}{2}} \quad \Sigma^{-} \quad {}^{-1/2} \exp\left[-1/2\ (x-\mu_0)'\Sigma^{-1}(x-\mu_0)\right]$$

Therefore, the ratio of $f_0(x)$ to $f_1(x)$ is:

$$\frac{f_0(x)}{f_1(x)} = \frac{(2\pi)^{-\frac{p}{2}} \quad \Sigma^{-1} \quad {}^{-1/2} \exp\left[-1/2\ (x-\mu o)'\Sigma^{-1}(x-\mu o)\right]}{(2\pi)^{-\frac{p}{2}} \quad \Sigma^{-1} \quad {}^{-1/2} \exp\left[-1/2(x-\mu_1)'\Sigma^{-1}\ (x-\mu_1)\right]}$$

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[1] The variance-covariance matrix Σ of a random variable x with mean μ is $E\ [(x-\mu)(x'-\mu')]$ where E is the expected value operator.

After cancellation, $\frac{f_0(x)}{f_1(x)}$ reduces to

$$\exp \quad - 1/2[(x - \mu o)' \, \Sigma^{-1} \, (x - \mu o) - (x - \mu_1)' \, \Sigma^{-1} \, (x - \mu_1)]$$

This implies that a case with predictor variable vector x would be classified in Group 0 if[1]

$$x^1 \Sigma^{-1} \, (\mu 0 - \mu 1) > 1/2 \, (\mu_0 + \mu_1)' \, \Sigma^{-1} \, (\mu_0 - \mu_1) + \ln \frac{(1 - \alpha)}{\alpha}$$ [1, 134]

This expression on the left-hand side of this inequality is the discriminant function, and the right side expression is the critical value of the discriminant function. If there is only one predictor variable the ratio of $f_0(x)$ to $f_1(x)$ becomes

$$\frac{fo(x)}{f_1(x)} = \frac{(2\pi\sigma^2)^{-1/2} \; \exp \, [-1/2\sigma^{-2}(x-\mu o)^2]}{(2\pi\sigma^2)^{-1/2} \; \exp \, [-1/2\sigma^{-2}(x-\mu_1)^2]}$$

$$= \exp \{-1/2\sigma^{-2}[(x-\mu o)^2 - (x-\mu_1)^2]\}$$

The region R_0 would consist of the set of all x such that

$$\exp \quad -1/2\sigma^{-2}[(x - \mu_0)^2 - (x - \mu_1)^2] > \frac{1 - \alpha}{\alpha}$$

Taking natural logs yields

$$- 1/2\sigma^{-2}[(x-\mu o)^2 - (x-\mu_1)^2] \quad \ln \frac{(1-\alpha)}{\alpha}$$

which in turn simplifies to

$$x\sigma^{-2}(\mu_0 - \mu_1) > 1/2 \, (\mu_0 + \mu_1)\sigma^{-2} \, (\mu_0 - \mu_1) + \ln \left(\frac{1 - \alpha}{\alpha}\right)$$

---

[1] This result follows from taking natural logarithms of both sides of the expression

$$\frac{f_0(x)}{f_1(x)} \quad \frac{(1 - \alpha)}{\alpha}$$

This is permissible because the natural logarithm is a monotonically increasing function.

If, for example, estimates from a sample set of data reveal that:

$$\alpha = .25$$

$$\mu_0 = -5$$

$$\mu_1 = 10$$

$$\sigma = 1$$

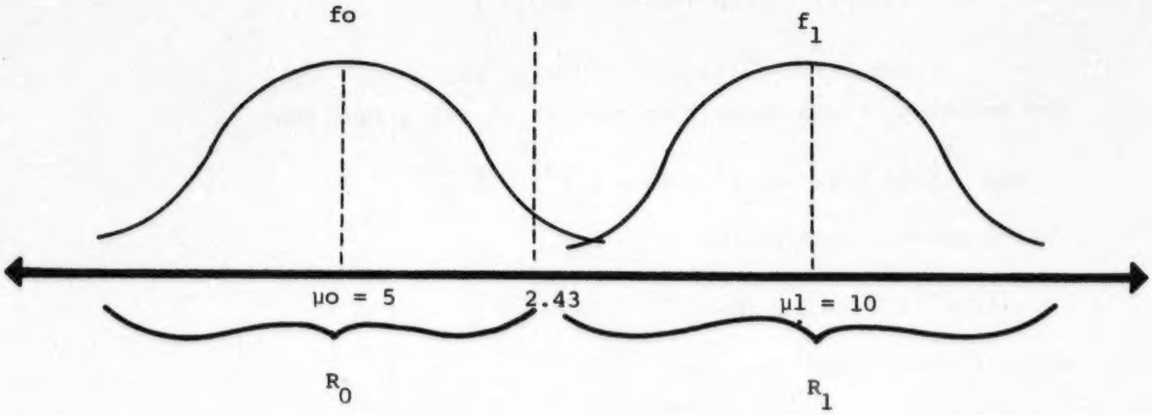
that region R_0 would consist of all x's for which the following inequality holds:

$$x(1)^{-2}\ (-5-10) > 1/2\ (-5+10)(1)^{-2}\ (-5-10) + \ln \frac{(.75)}{.25}$$

$$-15x > -37.5 + 1.04$$

$$x < 2.43$$

A value of the predictor variable x less than 2.43 indicates that a case more likely comes from Group 0 than Group 1. This conclusion is illustrated below:



Given an observation on the elements in the vector of predictor variables x the conditional probability of x coming from Group 0 is

$$\frac{f_0(x)}{\alpha f_0(x) + (1 - \alpha) f_1(x)}$$

Similarly, the conditional probability of coming from Group 1 is

$$\frac{(1 - \alpha) f_1(x)}{\alpha f_0(x) + (1 - \alpha) f_1(x)}$$

Note that the sum of these two conditional probabilities is equal to 1, and classifying a case into (say) Group 0 is equivalent to saying that the conditional probability of coming from Group 0 is larger than coming from Group 1. It must be true that

$$\alpha f_0(x) > (1 - \alpha) f_1(x)$$

if a case is to be classified into Region R_0. Therefore, it also is true that the conditional probability of a case coming from Group 0 must exceed the conditional probability of the case coming from Group 1. This follows from the formulas defining the conditional probabilities. If the vector of predictor variables is multivariate normal, the conditional probability of x coming from Group 0 is:

$$\frac{\alpha f_o(x)}{\alpha f_0(x) + (1 - \alpha) f_1(x)} =$$

$$\frac{\alpha \exp[-1/2(x- \mu o)'\Sigma^{-1}(x-\mu o)]}{\alpha \exp[-1/2(x-\mu o)'\Sigma^{-1}(x-\mu o)] + (1-\alpha)\exp[-1/](x-\mu_1)\Sigma^{-1}(x-\mu_1)}$$

The latter conditional probability is denoted by P(0/x). This notation is read "the conditional probability of classifying a case into Group 0 given x." The conditional probability of classifying into Group 1 is P(1/x). The relationship between these conditional probabilities is that P(0/x) + P(1/x) = 1.

Once we have estimates of α, μ_0, μ_1, and Σ we can calculate the conditional probabilities P(0/x) and P(1/x) for any vector of predictor variables. This procedure would be reversed in the following sense. Suppose α, μ_0, μ_1, and Σ have been estimated as well as all, but one, of the components of the x vector. Let the components of x be $x_1, x_2, \ldots, x_p$ and suppose $x_2, \ldots, x_p$ are known but x_1 is unknown. If P(0/x) is specified it is possible to calculate the value of x_1 that is consistent with the P(0/x). In this study, $\ln P_L$, lnV, and $(\ln V)^2$ are the components of x. The values of α, μ_0, μ_1, and Σ are estimated from our sample of 195 lakes and values of P(0/x) and P(1/x) are probabilities of a lake being oligotrophic and eutrophic, respectively. For example, the value of P(0/x) may be only .01 for a particular lake. Now we ask the question: What is the level of $\ln P_L$ (and P_L itself) that is consistent with some other value of P(0/x)? If we set P(0/x) = .75, we can calculate the P_L value that would be consistent with that probability level. Of course, the value of P_L consistent with $P(0/x) = .75$ would be much lower than the P_L level that is consistent with $P(0/x) = .01$.

The computational procedure for P_L for a certain value of $P(0/x)$ is given below:

Let

$$\begin{matrix} v \equiv x - \mu o \\ \\ w \equiv x \quad \mu_1 \end{matrix} \quad \text{where } x \equiv \begin{matrix} x_1 \\ x_2 \\ x_3 \end{matrix} \equiv \begin{matrix} \ln P_L \\ \ln V \\ (\ln V)^2 \end{matrix} \qquad \mu o \equiv \begin{matrix} \mu_{o1} \\ \mu_{o2} \\ \mu_{03} \end{matrix} \qquad 1 \qquad \begin{matrix} \mu_{11} \\ \mu_{12} \\ \mu_{13} \end{matrix}$$

then $P(o/x) = \dfrac{\alpha \exp(-1/2 v' \Sigma^{-1} v)}{\exp(-1/2\ v' \Sigma^{-1} v) + (1-\quad) \exp(-1/2 w'\ ^{-1} w)}$

The latter formula implies that

$$(v-w)' \Sigma^{-1} (v+w) = 2 \ln \quad \frac{\alpha(1-p)o \quad x)}{\alpha P(o \quad x)}$$

Finally, the value of x_1 is

$$x_1 = \frac{2 \ln k + c_2}{c_1}$$

where $k = \dfrac{\alpha[1-P(o/x)]}{(1-\alpha)\ P(o/x)}$

$$c_1 = 2\ \sigma_{11}(\mu_{11} - \mu_{o1}) + 2[\sigma_{12}\ (V_2 - w_2) + \sigma_{13}\ (v_3 - w_3)]$$

$$C_2 = \sigma_{11}(\mu_{11}{}^2 - \mu_{o1}{}^2) + 2[\sigma_{12}\ (\mu_{01}\ v_2 - \mu_{11}\ w_2) + \sigma_{13}(\mu_{01}\ v_3 - \mu_{11}\ w_3)$$

$$+ \sigma_{23}(w_2\ w_3 - v_2\ v_3)] + \sigma_{22}\ (w_2 - v_2{}^2) + \sigma_{33}\ (w_3{}^2 - v_3{}^2)$$

and

$$\Sigma^{-1} = \begin{matrix} \sigma_{11} & \sigma_{12} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{matrix} \quad \text{is symmetric}$$

Once x_1 is determined, an anti-log is taken to find P_L i.e.,

$$x_1 = \ln P_L$$

$$P_L = \exp\ (x_1)$$

An Example

Consider the case of only one predictor variable as an example of the foregoing computational procedure for finding the P_L level that is consistent with a specified value of P(o/x). As before, let $\alpha = .25$, $\mu o = -5$, $\mu_1 = 10$ and $\sigma = 1$. Let us find the value of x that is consistent with a 90% probability of Group 0 membership, i.e., P(0/x) = .90.

$$x = \frac{2 \ln k + c_2}{c_1}$$

where

$$k = \frac{.25(1- .90)}{(1- .25)(.90)} = .037$$

$$c_1 = 2\ (1)\ (10-5) = 10$$

$$c_2 = (1)[10-(-5)] = 15$$

The value of x is

$$x = \frac{2(.037)+15}{10} = 1.507$$

Therefore, the probability of Group 0 membership would be 90% if the value of x is 1.507. Recall, from the previous example, that any value of x less than 2.43 would lead to a Group 0 classification, whereas the probability would be 90% that an observation belongs to Group 0 is x = 1.507. This is a reasonable result since 1.507 is well within the interior of R_o (see Figure 2). In general, the larger the specified value of P(o/x), the smaller would be the value of x that would be consistent with P(o/x).

REFERENCES

1. T. W. Anderson, An Introduction to Multivariate Statistical Analysis, New York: Wiley, 1958.

2. R. E. Frank, W. F. Massy and D. G. Morrison, "Bias in Multiple Discriminant Analysis," Journal of Marketing Research, Autust, 1965, 2, 250-258.

3. R. V. Hogg and A. T. Craig, Introduction to Mathematical Statistics, New York: Macmillan, 1965.

4. G. Morrison, "On the Interpretation of Discriminant Analysis," *Journal of Marketing Research*, May, 1969, 6, 156-163.

5. M. M. Tatsuoka, *Multivariate Analysis*, New York: Wiley, 1971.

APPENDIX 5

A Note on the Discount Rate

Costs and benefits have been discounted at alternative rates of 8, 9, and 10% in this report. In doing so, we follow Krutilla and Fisher, who say: "discount rates of 8, 9, and 10% were used in the analysis because there appeared to be evidence that the opportunity costs of capital would fall within this range over the construction period of the projects" (6, p. 100). Reporting on another study in the same volume, the authors "have relied on a frequently used discount rate of 10% with sensitivity checks made using alternatively 7 and 13%" (6, pp. 167-81). Rates of 8 and 12% are used elsewhere "for testing the sensitivity of the conclusions to the estimates of the appropriate discount rate (10%)" (6, p. 243).

As Harberger points out, the appropriate rate of discount is derived as a weighted average of the private-sector marginal productivity of capital and the social rate of time preference (5, p. 95). When funds are diverted from the private to the public sector, a certain portion will have been diverted from capital investment. A foregone return on the sacrificed private capital formation is part of the opportunity cost of the public project. The before-tax marginal productivity of capital is a measure of this cost.

To the extent that private savings are diverted into the public project, a measure of their value in alternative uses is required. The supply price of savings, or after-tax social rate of time preference, is the required measure.

As a simplified example, suppose that the single after-tax rate of return on private investment is 7.75%, and the before-tax return to private savers is 6%. Additionally, suppose that the corporate tax rate is 50% and the average marginal tax rate on personal income is 25%. Consequently, the before-tax corporate return is 15.5% and the after-tax personal return is 4.5%; these are the relevant figures needed in calculating the discount rate.

If the two rates are weighted equally, the discount rate we arrive at is 10%. In general, the marginal productivity of capital receives a greater weight.

For an alternative presentation, along similar lines see (7, Chapters 31-34, 40).